SCALABILITY OF THE AIR TRANSPORTATION SYSTEM AND DEVELOPMENT OF MULTI-AIRPORT SYSTEMS: A WORLDWIDE PERSPECTIVE

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This report is based on the Doctoral Dissertation of Philippe A. Bonnefoy submitted to the Engineering Systems Division in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the Massachusetts Institute of Technology.

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ABSTRACT

With the growing demand for air transportation and the limited ability to increase capacity at some key points in the air transportation system, there are concerns that in the future the system will not scale to meet demand. This situation will result in the generation and the propagation of delays throughout the system, impacting passengers' quality of travel and more broadly the economy. This thesis proposes the investigation of the mechanisms by which the air transportation system has scaled to meet demand in the past and is expected to do so in the future using a multi-level engineering systems approach.

The air transportation system was first analyzed at the U.S. national level using network abstractions. In order to investigate limits in scaling of the U.S. air transportation network, theories of scale-free and scalable networks were used. It was found that the U.S. air transportation network was not scale-free due to capacity constraints at major airports, also preventing it from being scalable. However, the construction and analysis of a new network for which sets of two or more significant airports that serve passenger traffic in a metropolitan region (i.e. multi-airport systems) were aggregated into single nodes showed that it was scale-free and scalable. These results were also supported by a time series analysis of airport and multi-airport system growth. These analyses demonstrated the importance of regional level scaling mechanisms (i.e. development of multi-airport systems) in the ability of the air transportation system to adapt and scale to meet demand.

Given the importance of multi-airport systems, an in-depth multiple-case study analysis of 59 multi-airport systems worldwide was performed. This analysis was used to

develop a feedback model that captures the fundamental processes that govern the evolution of multi-airport systems.

Multi-airport systems were found to evolve according to two fundamental mechanisms: (1) the construction of new airports and (2) the emergence of secondary airports through the use of existing non-utilized airports. Several differences and similarities in the occurrence of these dynamics were identified across world regions. It was found that in the United States and Europe, the construction of new large airports occurred prior to or during World War II and to a minor extent during the 1960s and 1970s. More recently, significant limitations to the development of new airports (e.g. opposition from local communities) and changes in the airline industry (e.g. emergence and growth of low-cost carriers) led multi-airport systems in the United States and Europe to evolve through the emergence of secondary airports. In the Asia-Pacific region, multi-airport systems have predominantly evolved through the construction of new airports, due to fewer available airports, high projections of demand and weaker opposition to the construction of airports.

The analyses and insights from this thesis were also used to analyze and better understand the evolution of future multi-airport systems and provide recommendations for infrastructure management policies and multi-airport system development strategies.

In the United States and in Europe, there is the need to protect non-utilized exiting airport infrastructure (both civil and military airports) that can later be used to accommodate demand through the emergence of secondary airports. In parts of Asia where the existing under-utilized airport infrastructure is weak and where projections of high volume of demand -with high uncertainty- are high, there is the need to apply a dynamic approach to develop multi-airport systems. This approach includes actions such as reserving land area for future airport development and keeping original airports open since this option has proven to be useful and successful in the other regions of the world (i.e. United States and Europe). In some parts of Asia, such as India, where the military airport infrastructure is more developed than in other parts, there is also the need, as in the United States and Europe, to protect these airports since they may become future secondary airports following the airport status conversion dynamics that were observed in Europe

ACKNOWLEDGEMENTS

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ACRONYMS & ABBREVIATIONS

Acronyms		Description
AAR	:	Average Arrival Rate
ACI	:	Airport Council International
ADR	:	Average Departure Rate
ATC	:	Air Traffic Control
ASK	:	Available Seat Kilometer
BAA	:	British Airport Authority
BTS	:	Bureau of Transportation Statistics (United States)
BJ	:	Business Jet
CFR	:	Code of Federal Regulations
CIS	:	Commonwealth of Independent States
CPI	:	Consumer Price Index
DOT	:	Department of Transportation (United States)
ESD	:	Engineering Systems Division (MIT)
ETMS	:	Enhanced Traffic Management System
FAA	:	Federal Aviation Administration
GDP	:	Gross Domestic Product
HDR	:	High Density Rule
HHI	:	Herfindahl-Hirschman Index
HR	:	Hourly Rate
ICAO	:	International Civil Aviation Organization
IFR	:	Instrument Flight Rules
ILS	:	Instrument Landing System
IMC	:	Instrument Meteorological Conditions
JPDO	:	Joint Planning and Development Office
LCC	:	Low-Cost Carrier
LJ	:	Light Jet
LP	:	Light Piston
MAS	:	Multi-Airport System
NAS	:	National Airspace System
NB	:	Narrow Body (Jet)
NextGen	:	Next Generation Air Transportation System (U.S. Initiative)
NPIAS	:	National Plan for Integrated Airport System
OD	:	Origin Destination
OEP	:	Operational Evolution Plan
RAS	:	Regional Airport System
RJ	:	Regional Jet
RPK	:	Revenue Passenger Kilometer
SD	:	System Dynamics
TAF	:	Terminal Area Forecast
TP	:	Turbo Prop
TRACON	:	Terminal Radar Approach Control
TS	:	Traffic Share
UAV	:	Unmanned Aerial Vehicle
VFR	:	Visual Flight Rules
VLJ	:	Very Light Jet
VMC	:	Visual Meteorological Conditions
WB	:	Wide Body (Jet)

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KEY DEFINITIONS

Available Seat-Kilometer (ASK)	Number of seats flown multiplied by the distance flown in kilometers (i.e. measure of airline capacity)
Emerging secondary airport	An airport that serves less that than 500,000 passengers per year or less than 1% of the traffic in the multi-airport system and that exhibits early signs of emergence (i.e. airport infrastructure improvements, entry of a low-cost carrier)
Multi-Airport System	A set of two or more significant airports that serve passenger traffic in a metropolitan region
National Airspace System	Complex network of interconnected systems that includes over 19,000 airports, 750 ATC facilities, and about 45,000 pieces of equipment (FAA, 2002)
Network	Interconnected group of elements
Node Degree	Number of incoming and outgoing arcs in and out of a node
Primary airport	An airport that serves more than 20% of the total passenger traffic in a multi-airport system
Revenue Passenger Kilometer	Passenger that generates revenues transported over one kilometer
Scale	(1) the size of a system, (2) the level of observation or description of a system
Scale-free	Topological characteristics of a network for which the degree (or weighted degree) distribution follows a power law
Scalability	(1) the ability of a system, network or process to change its scale in order to meet growing volumes of demand (general definition)

	(2) the ability of a system to maintain its performance and function, and retain all its desired properties when its scale is increased greatly without having a corresponding increase in the system's complexity (more restrictive definition)
Scalable network	Network that can change scale in order to meet growing volumes of demand
Secondary airport	An airport serving between 1% and 20% of the total passenger traffic served in the multi-airport system (and serving more than 500,000 passengers per year)
Significant airport	An airport that serves more than 500,000 passengers per year and 1% of the total passenger traffic in a metropolitan region
Topology	Description of the relationship between components of a system or a network
Under-utilized airports	An existing airport located in a metropolitan region and that serves less than 500,000 passengers or 1% of the total passenger traffic served in the multi-airport system.
Weighted degree	Degree of a node weighted by the flows on incoming and outgoing arcs

CHAPTER 1

INTRODUCTION

1.1 Motivation

One of the greatest challenges faced by the air transportation system is increasing its scale in order to meet growing demand. Historically, passenger traffic has grown significantly. As shown on Figure 1, the two largest markets in terms of passenger traffic; North America and Europe have grown at an average annual rate of 5.7% and 5.0% respectively over the last 20 years. Asia-Pacific has also exhibited significant growth with an 8.8% average annual growth rate. This market is now reaching passenger traffic levels comparable to the European market. More recently, impressive growth of traffic has been observed in the Middle East exhibited an average annual growth rate of 13% per year between 2000 to 2007.

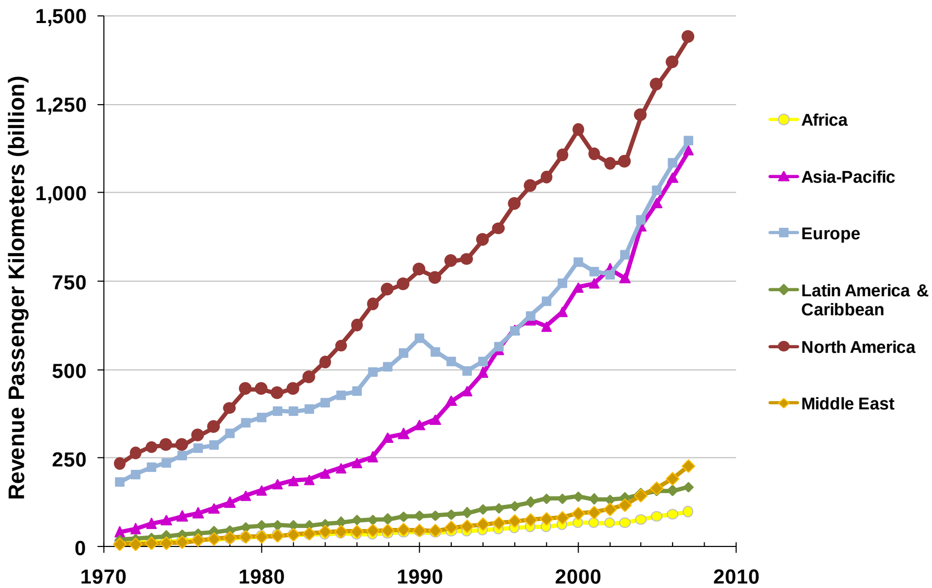

Figure 1: Historical evolution of air transportation activity (Revenue Passenger Kilometers) across six world regions from 1971 to 2007[1]

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[1] Data source: International Civil Aviation Organization (ICAO), Civil Aviation Statistics of the World, ICAO Statistical Yearbook, ICAO, Table 1-16 (1986 to1987), Table 1-13 (1998 to 1999), Annual Review of Civil Aviation 2001, 2002, 2003, ICAO Journal, vol. 57 No.6 2002, vol. 58, No. 6 2003, vol. 59, No. 6 2004, vol. 60, No. 6 2005, vol. 61 No. 6 2006 and International Air Transport Association (IATA) data for years 2005 to 2007.

Current long term forecasts indicate that demand for air transportation is likely to continue to grow. In its Aerospace Forecasts FY 2006-2017, the Federal Aviation Administration (FAA) projected growth rates of passenger traffic of 4.3% per year (FAA, 2005). In 2007, Boeing was projecting annual growth rates of Revenue Passenger Kilometers (RPK) of 4.2% for Europe, 8.0% for China and 6.9% for South East Asia over the next 20 years (BCA, 2007).

Future and sustained growth of traffic in these regions assumes that the airport infrastructure capacity is also able to grow in order to accommodate future demand. Even though the total airport system capacity is far greater than the combined number of operations, passenger and aircraft traffic are concentrated at key points in the system. For instance, in the United States, 80% of the air carrier operations[1] are handled at the top 50 airports[2] which accounts for 4% of usable airports. Similarly, 80% of the total itinerant operations[3] are handled at 820 airports[4] which accounts for 8% of usable airports.

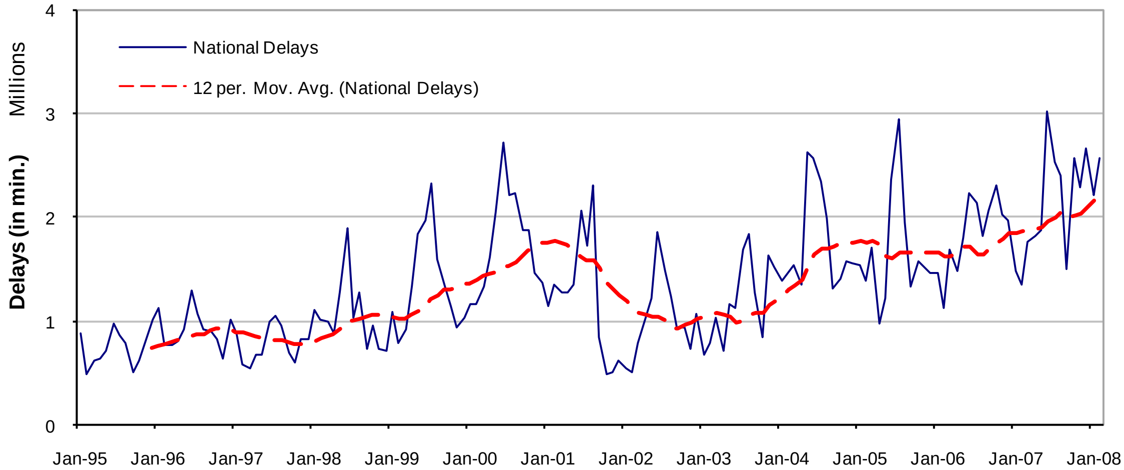
The growing volume of operations at major airports coupled with limited capacity at these airports result in congestion which materializes in the form of delays. These delays propagate throughout the air transportation network and affect the overall performance of the system. Figure 2 shows the evolution of monthly delays in the United States from 1990 to 2007 and its 12-month moving average.

[1] Data source: Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: March 2007.

[2] Note: 50 top airports with runways longer than 5000 ft were used to compute the percentage of usable airports for air carrier operations.

[3] Note: Itinerant operations defined by the FAA as; operations not classified as "local". The FAA defines local operations as operations remaining in the local traffic pattern, simulated instrument approaches at the airport, including the following subcategories, and operations to or from the airport and a practice area within a 20-mile radius of the tower; (1) Military: All classes of military operations, (2) Civil: All civilian operations, including local flights by air carrier and air taxi aircraft.

[4] Note: 820 top airports with runways longer than 3000 ft were used to compute the percentage of usable airports for total itinerant operations respectively.



Data source: US Federal Aviation Administration (FAA) OPSNET data.
Note: Due to the way delays are defined and are reported, OPSNET data underestimates the true extent of delays.
The use of this data in this figure is for trend analysis purposes (cf. footnote for additional details on OPSNET data).

Figure 2: Monthly delays in the United States from 1995 to 2008[1]

In the 1990s, passenger and aircraft traffic increased and peaked in 2000. Concurrently, delays also peaked in 2000. As a result of the slowdown of the economy and Sept. 11 events, passenger and aircraft traffic decreased in 2001 which relieved pressure on the system thus decreased delays. However, starting in 2003 the general increase in number of operations resulted in an increase in delays that reached a record level in 2007 compared to previous years. According to Airline Service Quality Performance (ASQP) for the top 75 airports in the United States, 24% of all arrivals in 2007 were delayed[2].

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[1] Data source: US Federal Aviation Administration (FAA), OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: April 2008. Note: For the purpose of delay trend analyses and comparative analyses of airport delays (i.e. location of delays), OPSNET data was used. It must be noted that OPSNET data reports underestimate the true extent of delays (El Alj, 2003). OPSNET data is maintained by the FAA through Air Route Traffic Control Centers (ARTCC) reports. Only flights with delays of 15 minutes or more are reported. A reportable delay recorded in OPSNET is defined in FAA Order 7210.55B as, "Delays to Instrument Flight Rules (IFR) traffic of 15 minutes or more, experienced by individual flights, which result from the ATC system detaining an aircraft at the gate, short of the runway, on the runway, on a taxiway, and/or in a holding configuration anywhere en route shall be reported." Such delays include delays due to weather conditions at airports and en route, FAA and non-FAA equipment malfunctions, the volume of traffic at an airport, reduction to runway capacity, and other factors. In addition, OPSNET does not report flight delays due to international causes (e.g. flights delayed at a center outside the United States). Airline Service Quality Performance (ASQP) is a source of data that provides a more accurate estimate of delays (i.e. percentage of operations delayed). However, time series analyses are limited with this dataset, since data is only reported after 1999 for major airports and 2004 for smaller airports (i.e. secondary airports).

[2] Data source: US Federal Aviation Administration (FAA), Aviation System Performance Metrics (ASPM), Airline Service Quality Performance (ASQP), available at: http://aspm.faa.gov/aspm/entryASPM.asp, last accessed; April 2008.

The generation of delays and their propagation throughout the system has negative impacts on passenger's quality of travel and more broadly the economy. Because the air transportation system is a vital underlying infrastructure of a country's economy, there is the need to find ways by which the system remains reliable, safe and efficient while meeting future demand. This motivates the need to investigate the mechanisms by which the air transportation system scaled to meet demand in the past and will do so in the future. In addition, understanding the implications of the evolution of the system is fundamental for guiding and informing policy decisions for the Next Generation of Air Transportation System in the United States and similar modernization and development efforts in other parts of the world.

1.2 Definition of the Problem

From first principles, there are two key levers that can be used to influence the airport congestion problem; (1) the *demand side* and (2) the *capacity side*. Figure 3 summarizes the set of solutions to address the airport congestion problem.

Fundamentally, there are several mechanisms by which the airport congestion problem can be addressed; (1) the "do nothing" alternative, (2) demand management, (3) scaling mechanisms (i.e. capacity increase, traffic shifts and efficiency improvement).

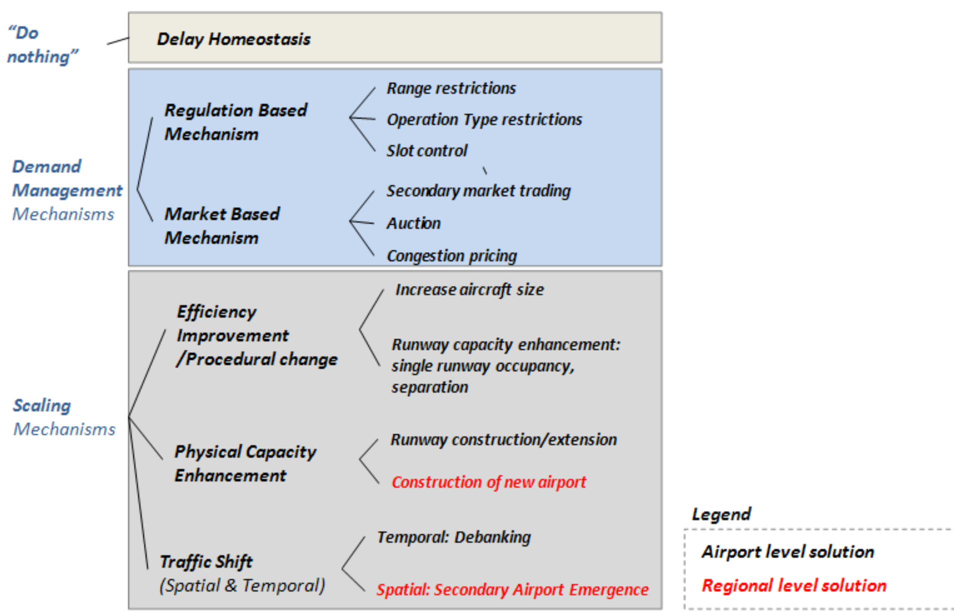

Figure 3: Set of solutions to address the airport congestion problem

1.2.1 Delay homeostasis

As presented in Figure 3, the “do nothing” option is based on a self regulating mechanism (i.e. delay homeostasis) where delays reach a level that airlines and passengers are willing to bear. In 2007, several airports around the world were not slot restricted and exhibited high level of delays (e.g. New York/Newark, San Francisco/Intl and New York/Kennedy) and are illustrating this mechanism. This mechanism assumes that as delays reach critical levels, passengers will change their travel behaviors and choose other airports (i.e. more attractive airports in the region if they exist) or switch to other modes of transportation. However, in some cases where delays reach high levels and the market is captive (i.e. alternative airports are not necessarily available and other modes of transportation are limited), need for intervention (e.g. demand management mechanisms) may arise. The case of New York/Kennedy, in late 2007 and early 2008, illustrates this dynamic.

1.2.2 Demand management

Demand management is a solution that addresses the demand/capacity problem. Its mechanisms can be (1) regulatory based or (2) market based.

Regulatory approaches to solving the airport congestion problem, can take the following forms; (1) setting airport capacity limit and allocating slots, (2) restricting the use of the airports (e.g. through range restrictions, traffic segregation using various criteria such as type of activity or nature of the flights). As of 2008, three airports were slot restricted in the United States; New York/LaGuardia, Washington/Reagan and Chicago/O'Hare. In addition, New York/LaGuardia has a range restriction that prohibits airlines from scheduling flights in and out to airports located more than 1500 miles from the airport. Washington/Reagan has a similar range restriction of 1250 miles. In 2007, Chicago/O'Hare had a restriction on general aviation (GA) flights with a maximum of 4 flights per hour.

Market based approaches can involve; (1) slot allocation by trading, (2) congestion pricing using a fixed fee structure, (3) auction based slot allocation.

While demand management solutions can limit the extent of the airport congestion problem, this solution does not increase the capacity of the system. In addition, limiting the growth of demand for air transportation has negative impacts (i.e. both direct and indirect impacts) on the economic performance of a region and ultimately a country. In the United States, the air transportation industry contributes to $80 to $90 billion per year to the national economy representing approximately 1% of the GDP and employs 800,000 people (NASA-FAA, 2003).

Both the delay homeostasis and the demand management mechanisms attempt to address the airport congestion problem by limiting demand and growth of traffic. However, they do not increase the capacity of the system and allow the system to meet increasing volume of passenger demand.

1.2.3 Scaling mechanisms

Scaling mechanisms represent a set of solutions that allow the system to scale and meet increasing demand. Fundamentally, there are two mechanisms by which a system can scale;

- *Scaling "up";* by increasing the size (i.e. capacity) of components of the system,
- *Scaling "out";* by changing the utilization of the components of the system (both temporally or spatially)

In addition, the ability of a system to scale (i.e. scalability) can be assessed for several components or layers of the system:

- Passenger (demand and traffic),
- Aircraft (air transportation networks),
- Infrastructure capacity (defined by physical infrastructure and procedures).

Figure 4 shows the several ways the air transportation system can scale based on the two fundamental scaling mechanisms. As shown on Figure 4, the air transportation network can scale "up" at the aircraft level by increasing the average size of aircraft or through procedures by reducing aircraft separation. It can also scale at the physical infrastructure level through the addition of capacity at airports (e.g. constructing new runways).

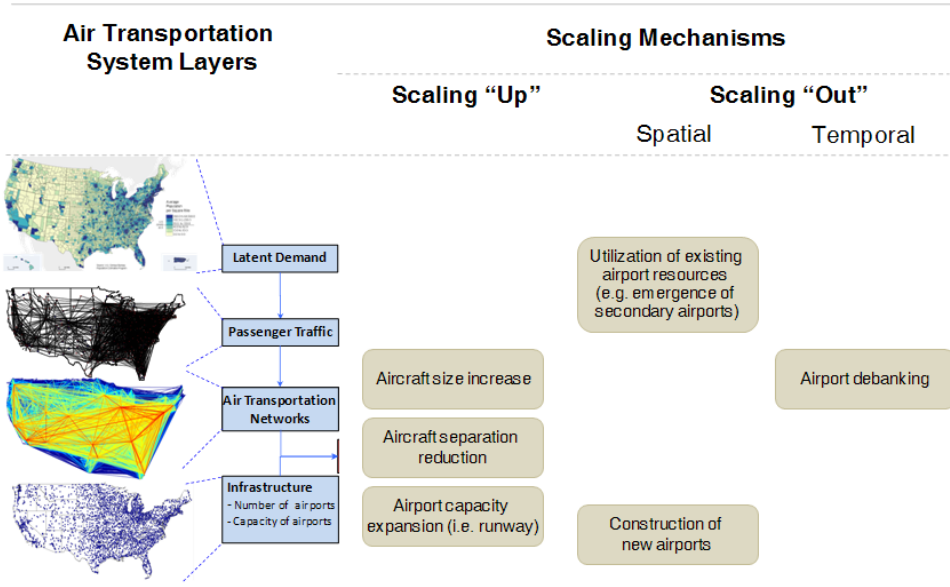

Figure 4: Scaling mechanisms in the air transportation system

a. Scaling "up": Increasing aircraft size

From a transportation system performance perspective the true technical metric of efficiency is the number of passengers carried by unit of capacity (i.e. airport/runway capacity). Therefore, all else being equal, utilizing larger aircraft would increase the airport passenger throughput while using the same airport and runway resources[1].

This mechanism is not being employed in the United States. In fact, evidence show that the average size of aircraft has been decreasing since 1990. The average number of seat per departure (i.e. aircraft size weighted by aircraft type utilization) has decreased from 130 to 88 seats between 1990 and 2007 for domestic operations[2]. This trend was the result of increased competition in the airline industry in the post deregulation era, the trend towards higher flight frequencies, and the entry and use of 50 to 90 seat Regional Jets (RJs) that started in the 1990s. This decreasing size of aircraft exacerbates the airport congestion problem. The use of regional jets is substantial at major airports such as

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[1] Note: Runways are generally the most constraining elements of an airport system and thus define the capacity of the airport (in terms of movement per hour).

[2] Data source: DOT Bureau of Transportation Statistics (BTS), Air Carrier Statistics (Form 41 Traffic)- All Carriers, T-100 Domestic and International Markets, available at: http://www.transtats.bts.gov/, last accessed; December 2007.

Chicago/O'Hare and New York/LaGuardia for which the traffic share[1] of regional jets was 43% and 32% respectively in 2005 (cf. Chapter 2 for details).

b. Scaling "up": Efficiency improvement and procedural changes

Another set of scaling dynamics involves local efficiency improvements. Efficiency can be improved at airports with mechanisms such as runway efficiency improvements, reduction of separation of aircraft on approach, simultaneous utilization of runways through the optimization of aircraft sequencing.

c. Scaling "up": Increasing capacity at major airports

To address the congestion problem, increasing capacity at congested airports is a key solution. In most cases, the runways are the most limiting component of an airport system. The ability to add runways can allow an airport to handle growing volumes of traffic. As shown on Figure 5, Atlanta Hartsfield (ATL) is a case of an airport at which capacity has been increased incrementally and met growing volume of traffic.

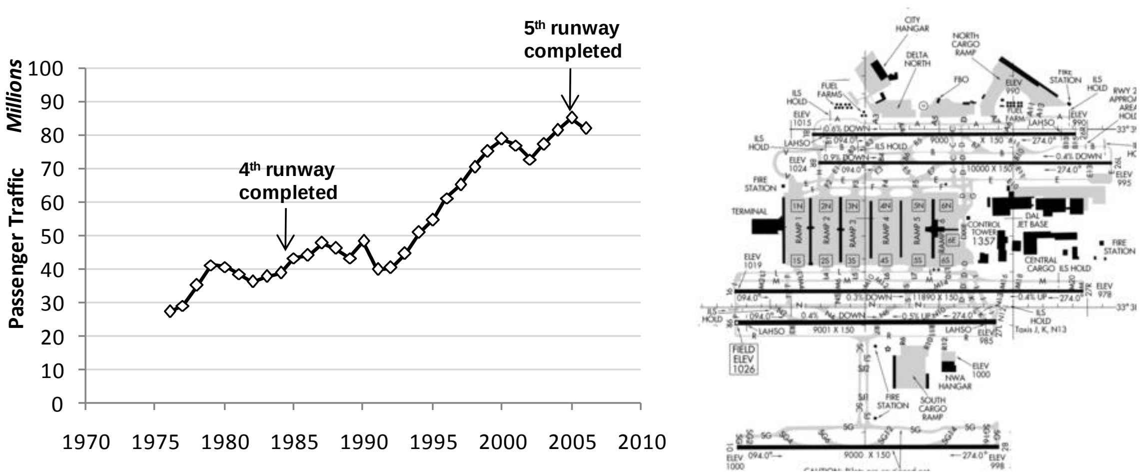

Figure 5: Historical evolution of passenger traffic and runway infrastructure improvements and map of Hartsfield-Jackson Atlanta International (ATL) airport

While the case of the construction of the fourth and then fifth runway at Atlanta Hartsfield is illustrative of a successful case of addition of significant capacity, it is generally difficult to add runway capacity at major airports. The case of the new runway (i.e. 14/32) at Boston/Logan that entered into service in November 2006 is a clear

[1] Data source: DOT Bureau of Transportation Statistics (BTS), Air Carrier Statistics (Form 41 Traffic)- All Carriers, T-100 Domestic Market, available at: http://www.transtats.bts.gov/, last accessed; December 2007.

illustration. The process, from initial intent to opening took approximately 30 years. In addition, this new runway only increased the capacity by approximately 3%, because it can only be used in one direction and in rare wind conditions.

The capability to increase capacity at major airports is generally limited due to factors such as lack of available space, environmental concerns, ground access limits and opposition from local communities.

The plans for airport capacity adjustment that are detailed in the FAA Operational Evolution Partnership (OEP) (FAA, 2008) do not fully address the congestion problem of major airports. Table 1 shows the OEP airports ranked by decreased percentage of delayed arrivals in 2007 and highlights the airports that will receive additional capacity in the upcoming years. Chicago/O'Hare which was ranked 7^{th} in terms of level of delays in 2007 will be the first airport in the list to receive additional capacity, mostly through the reconfiguration of its runway system. The following airports are ranked 8^{th}, 10^{th} and 15^{th}. Clearly the capacity adjustment plans leave the opportunity for many critical airports to continue to exhibit congestion problems and high level of delays. In addition, several regions are likely to lack capacity in the next years. The high density New York airport system with its three major airports (ranked 1^{st}, 2^{nd} and 3^{rd} in terms of delays) are not scheduled to receive any capacity improvement.

Table 1: New runway expansion projects at major airports (OEP airports) in the United States (ranked by decreasing arrival delays in 2007)[1]

Airport code	Airport name	Percentage of arrivals delayed in 2007 (ASQP data)	OEP new runway project (scheduled for 2008 and beyond)
EWR	New York/Newark	35.3	
LGA	New York/LaGuardia	34.9	
JFK	New York/Kennedy	33.2	
PHL	Philadelphia	27.9	
BOS	Boston/Logan	27.0	
SFO	San Francisco/Intl	26.8	
ORD	Chicago/O'Hare	26.6	Runways (9L/27R - 10L/28R - 20C/28C)
IAD	Washington/Dulles	24.9	Runway (1W/19W)
MIA	Miami/Intl	24.6	
SEA	Seattle	23.8	Runway (16X/34X)
PIT	Pittsburgh	23.8	
FLL	Miami/Fort Lauderda	23.7	
ATL	Atlanta	23.5	
MSP	Minn./St. Paul	23.0	
CLT	Charlotte	22.8	Runway (17/35)
MDW	Chicago/Midway	22.5	
MEM	Memphis	22.3	
BWI	Washington/Baltimor	22.2	
CLE	Cleveland	22.0	
TPA	Tampa/Intl	21.8	
LAS	Las Vegas	21.6	
LAX	Los Angeles/Intl	21.4	
DFW	Dallas/Fort Worth	21.4	
MCO	Orlando/Intl	21.3	
DTW	Detroit	21.2	
DEN	Denver/Intl	21.1	
DCA	Washington/Reagan	20.9	
STL	St Louis/Lambert	20.3	
PDX	Portland	20.0	
SAN	San Diego	19.6	
SLC	Salt Lake City	19.5	
PHX	Phoenix	19.4	
IAH	Houston/Intercontine	19.2	
CVG	Cincinnati	18.5	

If the growth of demand for air transportation is maintained and the system is operated under the same patterns of traffic concentration, key airports are expected to exhibit severe capacity shortage in the upcoming years.

In the forward looking FACT II study (FAA, 2007), the FAA identified potential airports and metropolitan regions that are likely to need additional capacity by 2025 (Figure 6). These planned improvements include; (1) new or extended runways (part of the OEP version 8.0 (FAA, 2008)), (2) new or revised Air Traffic Control (ATC) procedures (including NextGen concept), (2) airspace redesign (FAA, 2007). Figure 6

[1] Data source: US Federal Aviation Administration (FAA), Aviation System Performance Metrics (ASPM), Airline Service Quality Performance (ASQP), available at: http://aspm.faa.gov/aspm/entryASPM.asp, last accessed; April 2008 and Federal Aviation Administration, Operational Evolution Plan, available at http://www.faa.gov/programs/oep/, last accessed: March 2008.

shows that there are still 14 airports and 8 metropolitan regions that will need additional capacity in 2025, beyond what is currently planned.

Figure 6: Airports and metropolitan regions needing capacity in 2025 after planned improvements [Source: (FAA, 2007)]

In the case where the planned improvements do not occur or are delayed the capacity needs will be even greater. Figure 7 shows those 27 airports and 15 metropolitan regions that will need additional capacity if the existing airfield configurations remain constant without any capacity improvements (FAA, 2007).

Figure 7: Airports and metropolitan regions needing capacity in 2025 if planned improvements do not occur [Source: (FAA, 2007)]

d. Scaling through temporal traffic shift

The utilization of an airport throughout a day is highly variable due to temporal demand patterns. Generally, early mornings and late afternoons exhibit high peaks of demand leaving middle of the day and nights low demand periods of activity. While this variation of traffic is the result of demand patterns (i.e. passengers' time of travel preferences) some of it is due to airline operating paradigms. At connecting hub airports airlines have operated successions of banks of arrivals and departures from one hour to several hours. Figure 8 illustrates the case of American Airlines operations at Dallas/Fort Worth (DFW). In 2000, American Airlines was operating its hub according to bank schedules (i.e. banks lasting approximately one hour).

While it is difficult to smooth passenger demand uniformly across the day and night because of passenger traveling constraints and preferences, over the last 5 years airlines have been actively debanking the operations at connecting hub airports by smoothing the operations across the day. At Dallas/Fort Worth, American Airlines converted its hub operations to a rolling bank schedule (Figure 8) by shifting some of the flights from the peaks to the trough. This change in operating pattern reduces the congestion during peak demand periods. Between 2001 and 2003, the percentage of delayed arrivals at Dallas/Fort Worth decreased by 17%[1]. During the same time interval, the total number of operations at Dallas/Fort Worth decreased by 8%[2]. The reduction in delays was therefore a combination of the debanking strategy but also to the decrease in traffic which has non-linear effects on delays.

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[1] Data source: US Federal Aviation Administration (FAA), Aviation System Performance Metrics (ASPM), Airline Service Quality Performance (ASQP), available at: http://aspm.faa.gov/aspm/entryASPM.asp, last accessed; April 2008.

[2] Data source: Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: April 2008.

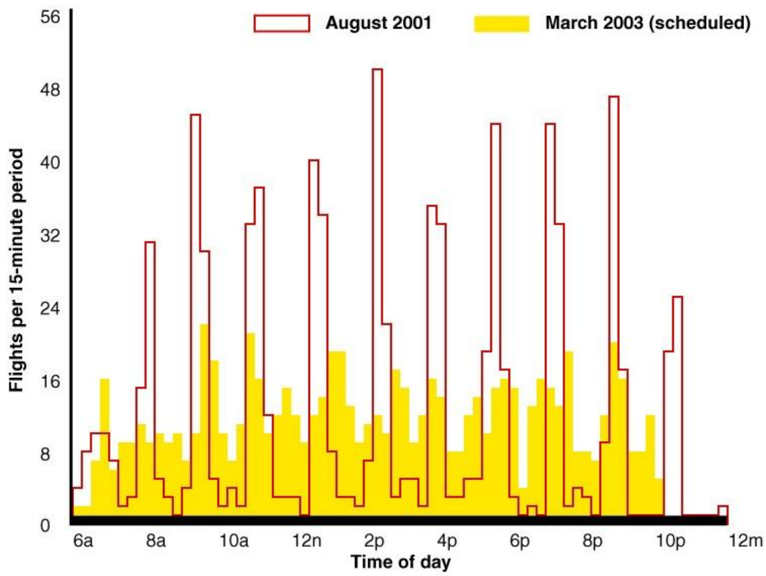

Figure 8: Temporal utilization of Dallas/Fort Worth (DFW) airport in 2001 and 2003; Effects of airport debanking policy [Source: (Tam, et al., 2002)]

Between 2000 and 2005, several other connecting hub airports have also been transformed into rolling hubs; Chicago/O'Hare by American Airlines, Atlanta Intl by Delta Airlines, Frankfurt/Main by Lufthansa.

e. Scaling "out"; spatial shift through the development of multi-airport systems

As shown on Figure 4, the air transportation system can also scale according to the scaling "out" mechanism that involves spatial shift of traffic through the construction of new airports or the emergence of existing airports into secondary airports.

Development of multi-airport systems through the construction of new airports

Another physical capacity enhancement mechanism (i.e. scaling "out" mechanism) involves the construction of new high capacity airports in the region. This regional level based mechanism has been observed in the United States in the 1970s with the construction of airports such as Washington/Dulles (IAD), Dallas/Fort Worth (DFW) and more recently with Denver/Intl (DEN) in the 1990s.

Development of multi-airport systems through the emergence of secondary airports

Traffic can also be shifted spatially through regional based scaling mechanisms that utilize existing (i.e. under-utilized) airport infrastructure resulting in the emergence of secondary airports. Over the last three decades, several key secondary airports have emerged in the United States serving demand for air transportation within a metropolitan region. Figure 9 shows all airports within 50 miles of Boston/Logan that have runways longer than 5000 ft.

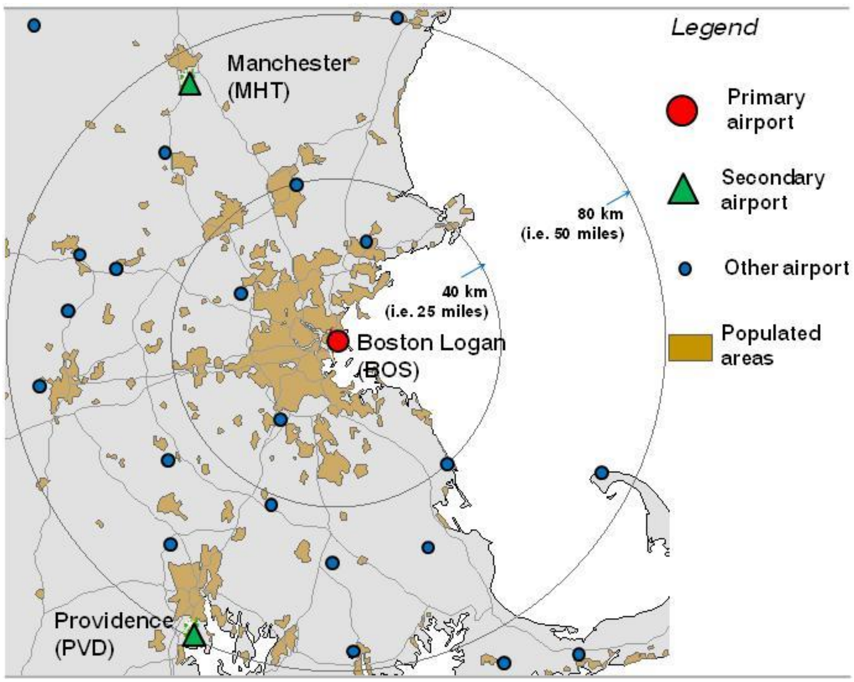

Figure 9: Primary, secondary and surrounding airports in the Boston metropolitan region

Boston/Logan (BOS) is the primary airport in the metropolitan region. The system is also composed of two secondary airports; Boston/Providence (PVD) and Boston/Manchester (MHT). In the close periphery of Boston/Logan, Hanscom Field (BED) serves mostly as a reliever airport for business aviation and is used for joint military/civil operations. In the 20 to 40 miles range, there are several small airports such as Beverly (BVY), Lawrence (LWM) and Pawtucket (SFZ).

Figure 10 shows the evolution of passenger traffic at Boston/Logan, Boston/Providence and Boston/Manchester. The increasing contribution of Boston/Providence and Boston/Manchester to the total passenger traffic (i.e. 26% in

2006) shows the effectiveness of this scaling mechanism for accommodating growing demand in a metropolitan region.

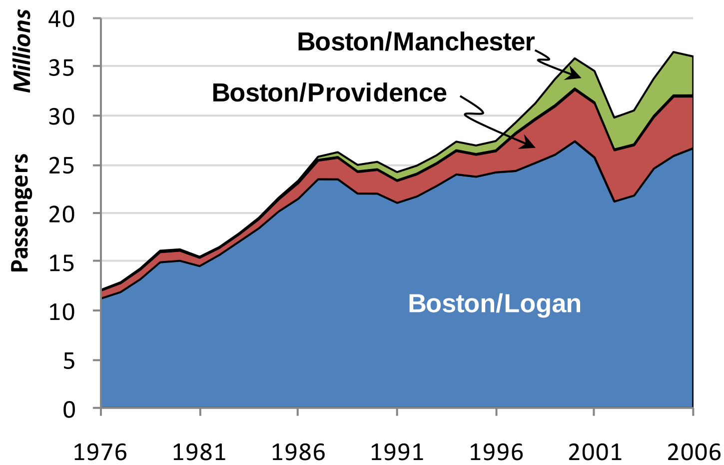

Figure 10: Evolution of passenger traffic at primary and secondary airports in the Boston metropolitan region[1]

1.2.4 Summary

With the growing demand for air transportation and the limited ability to increase capacity at some key points in the air transportation system, there are concerns that, in the future, some parts of the system will not scale to meet demand. This situation will result in the generation and the propagation of delays throughout the system, impacting passengers' quality of travel and more broadly the economy. Several mechanisms have been presented to address the airport congestion problem; (1) the "do nothing" alternative, (2) demand management, (3) scaling mechanisms. Scaling mechanisms were the only mechanisms identified that allowed the system to meet increasing demand. In addition, given the capacity constraints on existing major airports, it seems that the development of multi-airport systems is going to be a key mechanism by which air transportation systems around the world will be able to meet future demand.

[1] Data source: Federal Aviation Administration (FAA), Historical records from the Terminal Area Forecasts, available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: March 2007.

1.3 Research Objectives

Given the motivation presented in the previous sections, the objective of this research was to (1) investigate how the air transportation system scaled in the past and was able to accommodate growing volumes of demand, (2) more specifically investigate the role of the development of multi-airport systems as a scaling mechanism, and (3) better understand the evolution and development of these systems and from this understanding derive insights as to how to better design, operate, manage them and allow their development in the future.

1.4 Outline of the Thesis

Chapter 2 provides background information on the air transportation system that is used to support the analyses presented in the following chapters.

Chapter 3 reviews the literature on the scalability of systems (i.e. air transportation system but also other types of engineering systems). It also reviews literature on network analysis and on multi-airport systems.

Chapter 4 outlines the multi-level holistic approach used to guide this research and that was motivated from the definition of the problem.

The core part of the thesis is presented in chapters 5 to 8. Chapter 5 presents the investigation of the limits to scale of the air transportation systems through network analysis building on theories of scale-free and scalable networks. Chapter 6 presents the multi-airport systems used as a basis for the multiple-case study analysis. In Chapter 7, the dynamics governing the evolution of multi-airport systems are then presented, based on the cases of multi-airport systems. Chapter 8 presents a feedback model of the evolution of multi-airport systems, along with the results of the analysis of the factors that influence the dynamics of multi-airport systems worldwide.

In Chapter 9, the implications of the findings of this study are analyzed to provide recommendations for the effective development of multi-airport systems in the future.

Finally, Chapter 10 presents the conclusions and contributions of this research.

CHAPTER 2

BACKGROUND ON THE AIR TRANSPORTATION SYSTEM

In the context of globalization, the air transportation system is more than ever critical to our society and economy by enabling flows of passengers and freight both domestically and internationally.

This chapter presents some background information on the air transportation system that supports the analyses that are presented in following sections of this thesis. The first part of this chapter describes the air transportation system at the high level (general system description). Then a spatial and network decomposition framework is used to present and discuss the performance of the components of the system. Finally, the global air transportation system is presented followed by a more detailed description of the U.S. air transportation system.

2.1 Conceptual Description of the Air Transportation System

2.1.1 High level description of the system

The air transportation system is a ***large-scale*** (i.e. extends geographically worldwide), ***complex*** (i.e. displays both structural and behavioral complexity), ***adaptive*** (i.e. exhibit change dynamics in response to continuous and punctual stimuli), ***socio-technical*** (i.e. has both social and technical components) ***system***. The primary function of the system is to provide domestic and international air transportation services for both passengers and freight. It is a system that is not isolated but rather interconnected with an external environment. As shown on Figure 11, the air transportation system is linked to the local, regional, national and international economy through a set of flows (i.e. financial, service, information) that form feedback loops. The air transportation system, by its fundamental nature, generates a supply of services (i.e. pricing and schedule) that impact the economy through economic enabling effects. It also provides direct, indirect and induced employment effects. In return, the economy provides demand (i.e. passenger and freight demand) that generates revenues to air transportation stakeholders (i.e. airlines, airports, suppliers, etc.). In addition, the financial markets provide equity and debt to air transportation service providers.

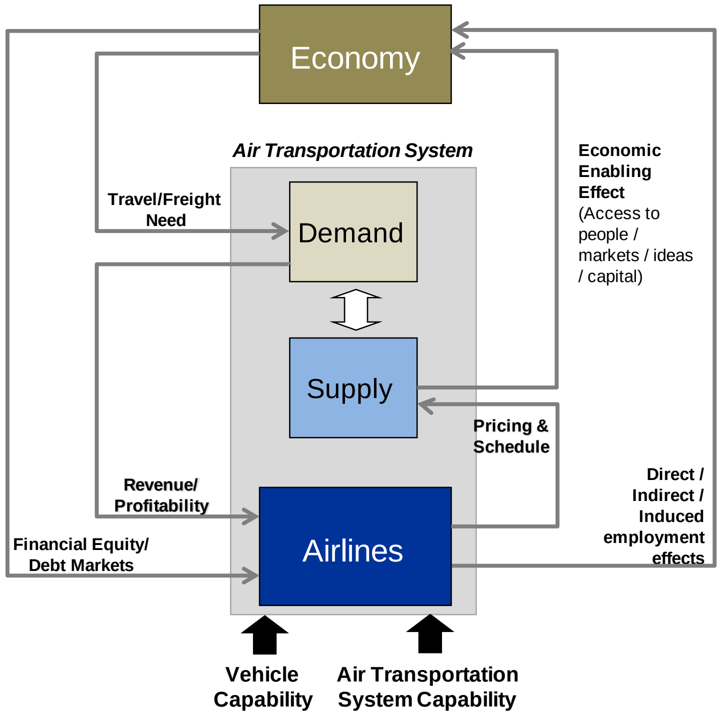

Figure 11: Relationship between the air transportation system and the economy [adapted from (Tam, 2003)]

2.1.2 System decomposition

Because the air transportation system is fundamentally a network system (i.e. composed of thousands of interconnected subsystems and parts), it can be described and represented using network abstractions. Figure 12 shows the spatial decomposition of the key components of the air transportation system. The spatial components of the system can be decomposed into several layers; latent demand, passenger flows, flights and aircraft flows (i.e. networks/supply) and infrastructure (i.e. airports). Latent demand is represented as a set of passenger itineraries (or packages for freight) from door-to-door origin-to-destination. This layer of the air transportation network is to first order driven by population distribution, socio-economic factors (e.g. discretionary income), and business center locations. The passenger flow layer is composed of a network of airport-to-airport flows of passengers and freight. This layer is tightly coupled with the aircraft flow network composed of airport-to-airport links flown by a wide range of aircraft types (i.e. from wide body jets, narrow body jets to business jets and general aviation aircraft). The traffic layer is supported by the infrastructure network, composed predominantly of a set of airports.

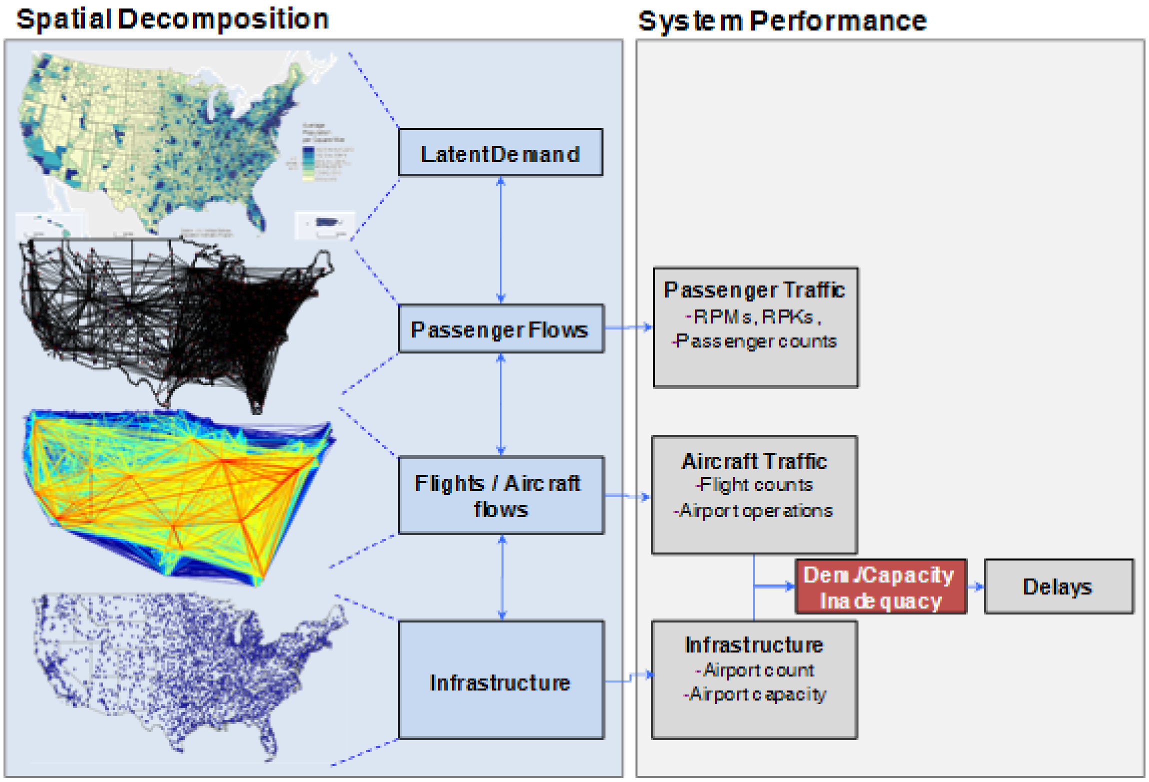

Figure 12: Conceptual spatial decomposition of the air transportation system with performance metrics at each network layer [layered spatial decomposition adapted from (Holmes, et al., 2004)]

In parallel to this spatial decomposition of the air transportation system, a system performance view of the system can be constructed (Figure 12). For each layer, several system attributes and performance metrics can be quantified and measured. These include passenger traffic (e.g. passenger volumes, RPKs), aircraft traffic (e.g. aircraft flows) and airports (e.g. number of airports, capacity of airports). Given the motivation of this research, the ratio of aircraft demand divided by airport capacity is a key metric. This ratio is also known in the air transportation literature as the airport utilization ratio (de Neufville, et al., 2003). Based on queuing theory models and actual traffic data analysis, delays are related to the airport utilization ratio through a non linear relationship (de Neufville, et al., 2003).

2.2 The Global Air Transportation System

The air transportation system representation and construct presented in Figure 12, is used to present systematically and logically the global air transportation system.

2.2.1 Distribution and evolution of passenger traffic

Figure 13 shows the historical evolution of passenger traffic measured in revenue passenger kilometers (RPKs) from 1971 to 2007. The two largest markets in terms of passenger traffic, North America and Europe have grown at an average annual rate of 5.7% and 5.0% respectively over the last 20 years. Asia-Pacific has also exhibited a significant 8.8% average annual growth rate. This market is now reaching traffic levels comparable to the European market. More recently, impressive rate of growth of traffic have been observed in the Middle East, reaching 13% per year from 2000 to 2007. This growth is mainly due to the emergence of new international network carriers such as Emirates, Etihad, Gulf Air and Qatar Airways which serve in part the connecting traffic from Europe to Asia-Pacific. Latin America and Africa have grown at slower rates.

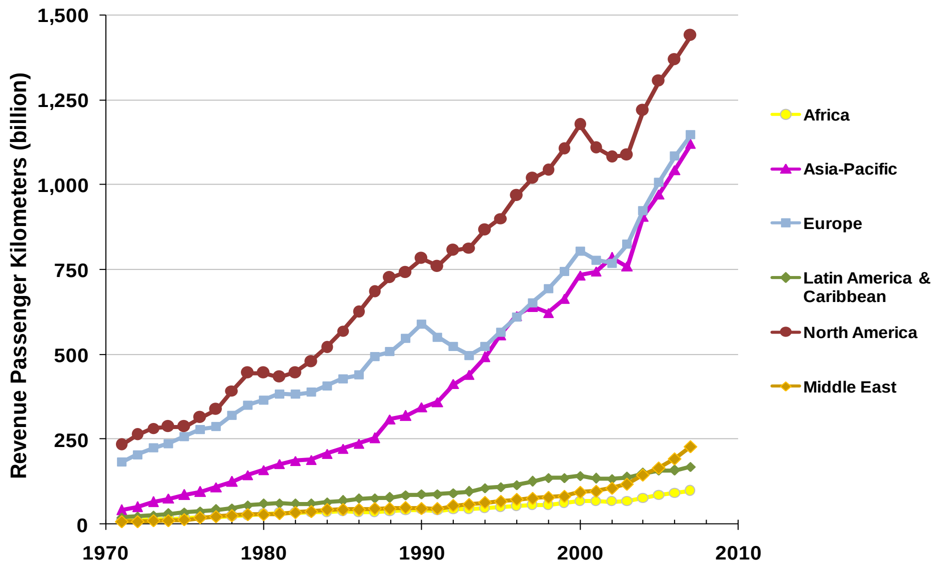

Figure 13: Historical evolution of passenger traffic (in Revenue Passenger Kilometers) across six world regions from 1971 to 2007[1]

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[1] Data source: International Civil Aviation Organization (ICAO), Civil Aviation Statistics of the World, ICAO Statistical Yearbook, ICAO, Table 1-16 (1986 to1987), Table 1-13 (1998 to 1999), Annual Review of Civil Aviation 2001, 2002, 2003, ICAO Journal, vol. 57 No.6 2002, vol. 58, No. 6 2003, vol. 59, No. 6 2004, vol. 60, No. 6 2005, vol. 61 No. 6 2006 and International Air Transport Association (IATA) data for years 2005 to 2007.

In terms of freight traffic (Figure 14), the largest market was Asia-Pacific, as of 2005, which exhibited rapid growth since the 1970s. Europe and North America, which are respectively the second and third market in importance, also grew significantly over the same time period. Similarly to passenger traffic, freight traffic in the Middle East has grown substantially during the last years.

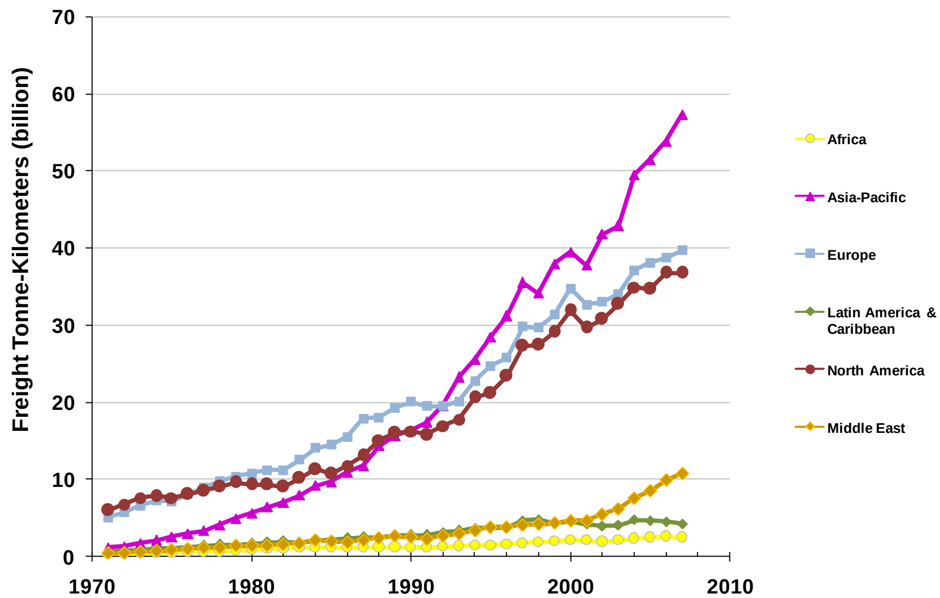

Figure 14: Historical evolution of freight traffic (in Freight Tonne-Kilometers) across six world regions from 1971 to 2007[1]

2.2.2 Aircraft fleet and flight network

The flight/aircraft flow network layer of the air transportation system is composed of two elements; the network of routes flown and the vehicles (i.e. aircraft) that fly on these routes. Figure 15 shows a density map of aircraft traffic worldwide. The United States, Europe and some parts of Asia exhibit dense traffic from which domestic traffic represents a significant share. In addition, traffic between continents is clearly observed (e.g. United States to Europe, Europe to Asia, and United States to Asia).

[1] Data source: International Civil Aviation Organization (ICAO), Civil Aviation Statistics of the World, ICAO Statistical Yearbook, ICAO, Table 1-16 (1986 to1987), Table 1-13 (1998 to 1999), Annual Review of Civil Aviation 2001, 2002, 2003, ICAO Journal, vol. 57 No.6 2002, vol. 58, No. 6 2003, vol. 59, No. 6 2004, vol. 60, No. 6 2005, vol. 61 No. 6 2006 and International Air Transport Association (IATA) data for years 2005 to 2007.

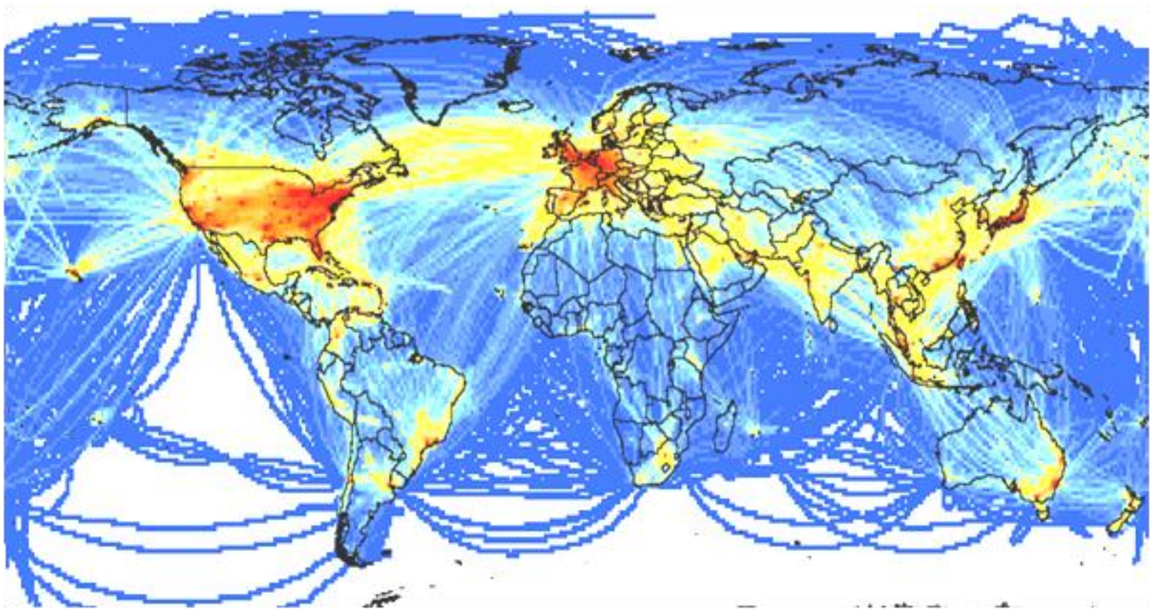

Figure 15: Output from the FAA System for assessing Aviation's Global Emissions (SAGE) showing the world-wide distribution of aircraft carbon dioxide emissions for 2000 (proportional to first order to density of flights) [Source: (Waitz, et al., 2004)]

There were 13,714 registered aircraft with 50 or more seats in service worldwide in 1999 (Transport Canada, 2004). Figure 16 shows the historical evolution of the number of aircraft worldwide from 1965 to 1999.

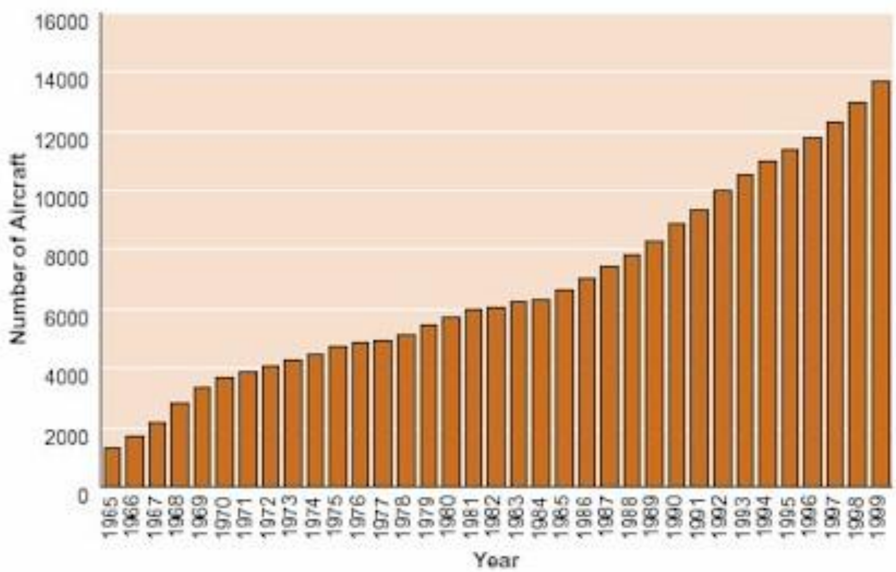

Figure 16: World airline aircraft fleet from 1965 to 1999 [Source: (Transport Canada, 2004)]

Figure 17 shows the geographic distribution of the aircraft fleet worldwide. The distribution of the worldwide fleet generally correlates with the distribution of traffic by world regions. The North American market (i.e. United States of America and Canada) represented 46.5% of the total world fleet, followed by Europe with 23.7% and Asia-Pacific with 15.2%.

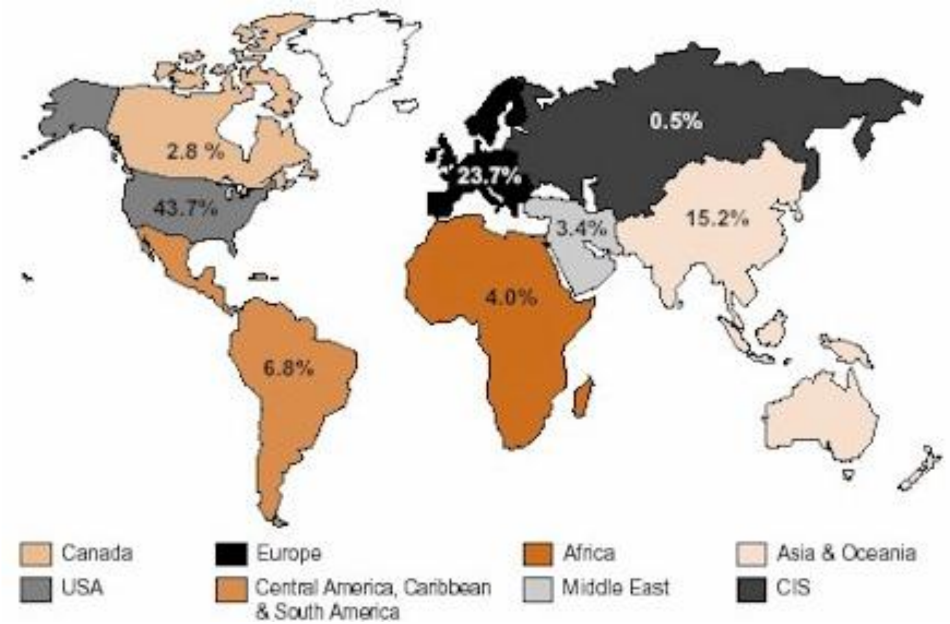

Figure 17: Geographic distribution of aircraft fleet (over 50 seats) worldwide in 1999 [Source: (Transport Canada, 2004)]

2.2.3 Airport infrastructure

The aircraft flow and flight layer of the air transportation system is supported by the infrastructure network, which is composed of set of airports and air traffic management facilities. In 2007, the worldwide airport network was composed of 45,813 airports of which 30% (i.e. 14,128 airports) had paved runways and 70% (i.e. 31,685 airports) had unpaved runways (CIA, 2007). Of the 14,000 airports with paved runways, 6,750 had at least one runway longer than 5,000 ft, which represents the set of airports that can be used by regional jets and some narrow body jets. As the runway length requirement is increase, the available worldwide airport network significantly reduces. Only 950 airports worldwide have at least one runway longer than 10,000 ft. The set of airports is not uniformly distributed across world regions and countries. As shown on Figure 18, the United States and Europe exhibit the densest network of airports.

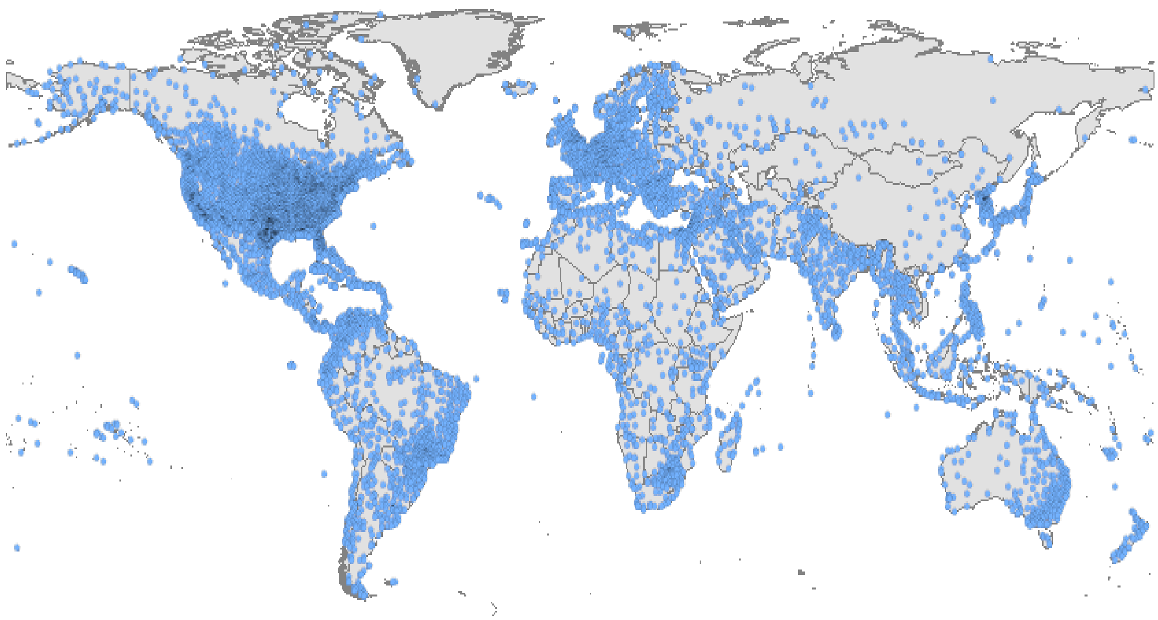

Figure 18: Geographical distribution of airports worldwide[1]

Figure 19 shows the distribution of the number of airports across different countries worldwide. The United States has the largest number of airports with 32% of the world airports. Brazil, Europe and Mexico also contribute significantly to the worldwide airport set.

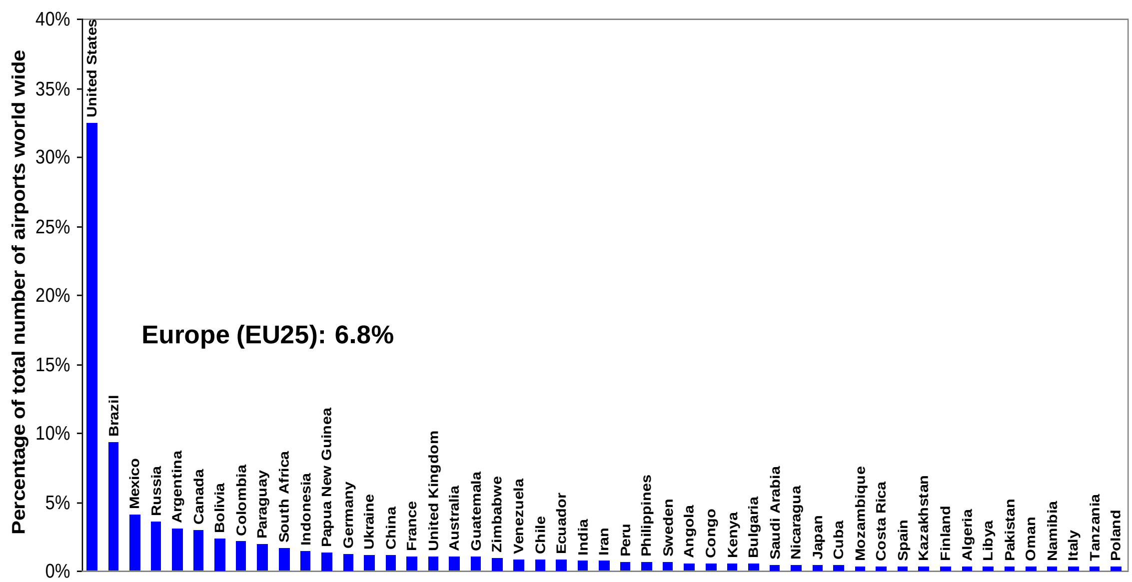

Figure 19: Distribution of airports by country[1]

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[1] Data source: Digital Aeronautical Flight Information File Database (DAFIF), (2005), National Geospatial-Intelligence Agency (NGA). Data plotted using ArcGIS® software.

2.3 The U.S. Air Transportation System

2.3.1 Distribution and evolution of passenger traffic

As shown on Figure 13, in 2005, the U.S. air transportation system handled 1,304 billion passenger-kilometers and 35 billion freight ton kilometers (ICAO, 2005). In terms of passenger traffic, total enplanements increased by a factor of 3 from 236 million enplanements in 1976 to 705 million in 2000 corresponding to an average growth rate of 4% per year (Figure 20).

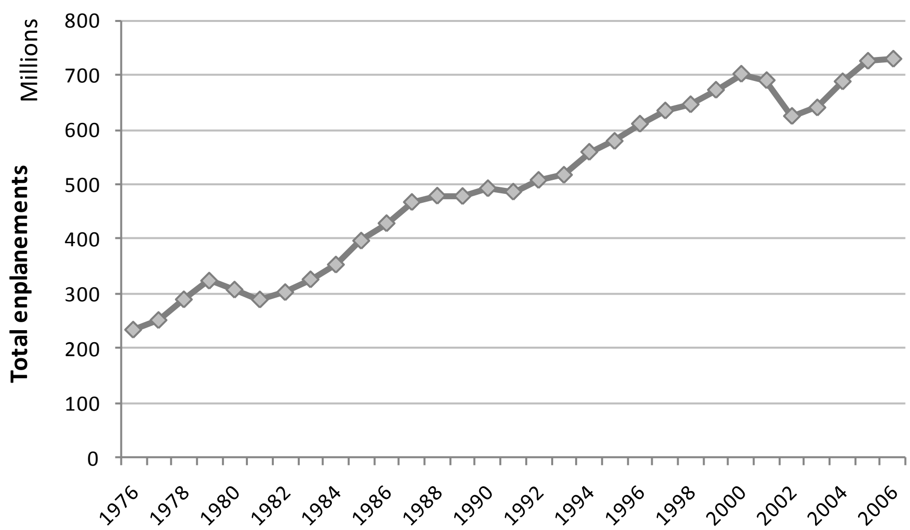

Figure 20: Historical evolution of total enplanements in the United States from 1976 to 2006[2]

The 11% decrease in passenger traffic between 2000 and 2002 resulted from the economic recession that started early 2001 and was later reinforced by the Sept 11 events. Since 2002, passenger traffic has been steadily increasing and exceeded 2000 traffic levels in 2005.

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[1] Data source: Central Intelligence Agency, The World Wide Fact Book, 2006, available at: https://www.cia.gov/library/publications/the-world-factbook/index.html, last accessed: December 2007.

[2] Data source: Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: March 2007.

2.3.2 Aircraft fleet and flight network

The flight/aircraft flow network layer of the air transportation system is composed of two elements; the network of routes flown and the vehicles that fly on these routes. Figure 21 represents the network of flights in the United States based on Enhanced Traffic Management System (ETMS) data of actual traffic that took place from October 1st 2004 to September 30th 2005[1]. As shown on Figure 21, the U.S. air transportation network is a dense network, with a large number of connections with low frequency and a few airport-to-airport connections with very high frequency.

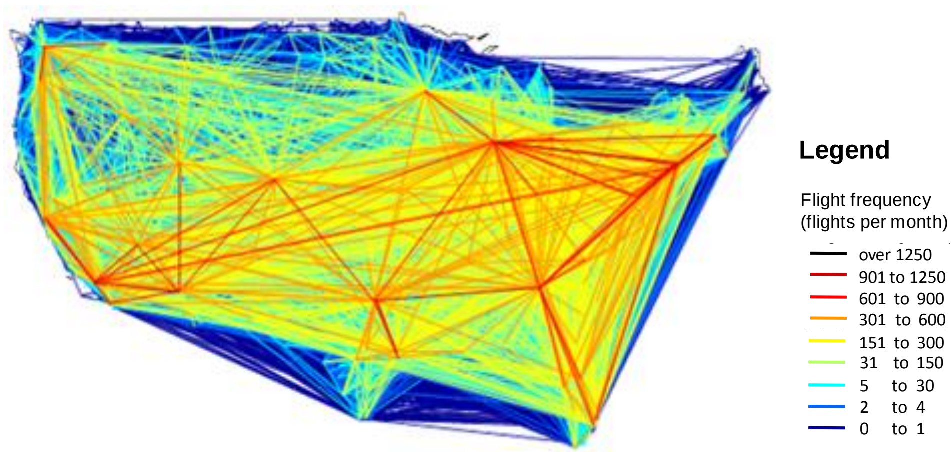

Figure 21: Domestic air transportation network in the United States[2]

Figure 22 shows the overall increase in total number of commercial operations in the United States from 1976 to 2006.

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[1] Note: Additional information on the data source and the construction of the graph can be found in Chapter 5: Network Theory based Investigation of the Scalability of the Air Transportation System

[2] Data source: FAA Enhanced Traffic Management System (ETMS), network corresponding to traffic data from October 1st 2004 to September 30th 2005.

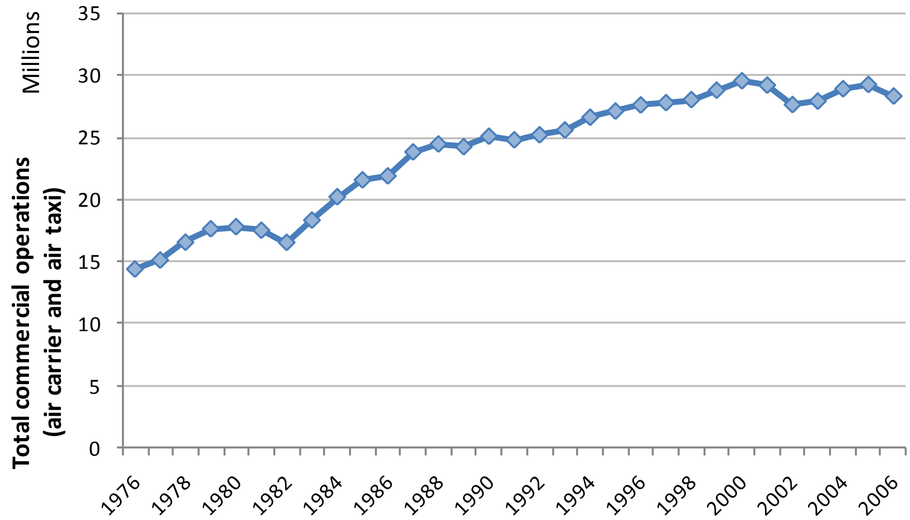

Figure 22: Historical evolution of total operations in the United States from 1976 to 2006[1]

Figure 23 shows the average number of seats per departure for domestic and international operations. With an average ratio of 7.2 domestic departures for each international departure, domestic operations drive the general aircraft fleet size in the United States.

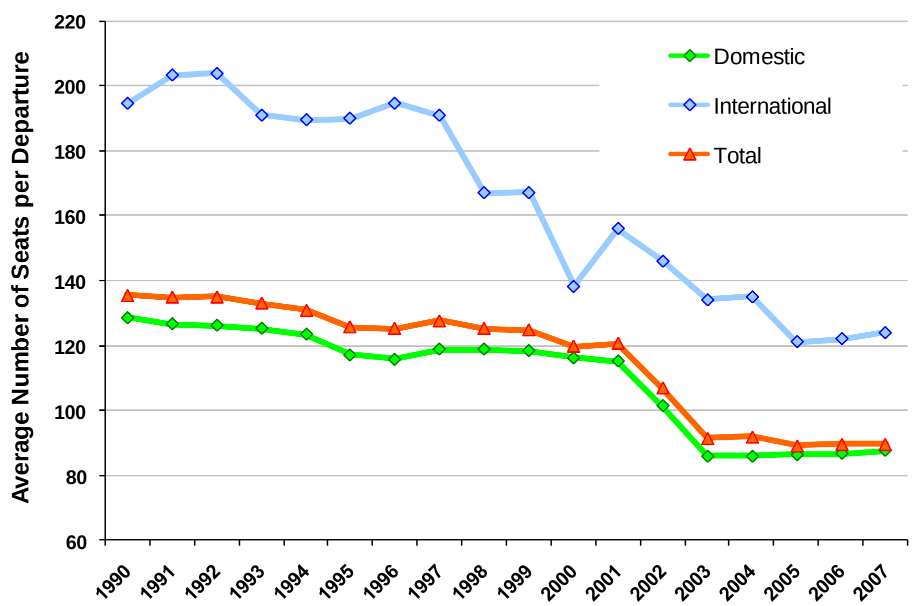

Figure 23: Historical evolution of average number of seats per departure from 1990 to 2007[1]

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[1] Data source: Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: March 2007.

The average number of seats per departure decreased constantly between 1990 and 2000. The reason underlying this trend was the entry of regional jets (i.e. 50 to 100 seat twin jet aircraft) that exhibited significant growth during the 1990s. This trend strengthened after 2000 when major carriers took the oldest and large aircraft out of their fleets during the airline industry downturn that started in early 2001 and was exacerbated by September 11 into an industry crisis.

Since 2004, the average number of seats per departure has leveled to approximately 85 for domestic operations.

The current and future development of business/corporate aviation operators (e.g. charter operators, fractional ownership operators) coupled with the entry of a new class of aircraft (i.e. Very Light Jets), used for commercial purposes could potentially affect the average size of aircraft.

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[1] Data source: DOT Bureau of Transportation Statistics (BTS), Air Carrier Statistics (Form 41 Traffic)- All Carriers, T-100 Domestic and International Markets, available at: http://www.transtats.bts.gov/, last accessed; December 2007.

2.3.3 Airport infrastructure

In January 2004, the U.S. airport system was composed of 19,576 airports of which 5280 were open to the public (FAA, 2005). Figure 24 shows the geographical distribution of airports in the United States in 2004.

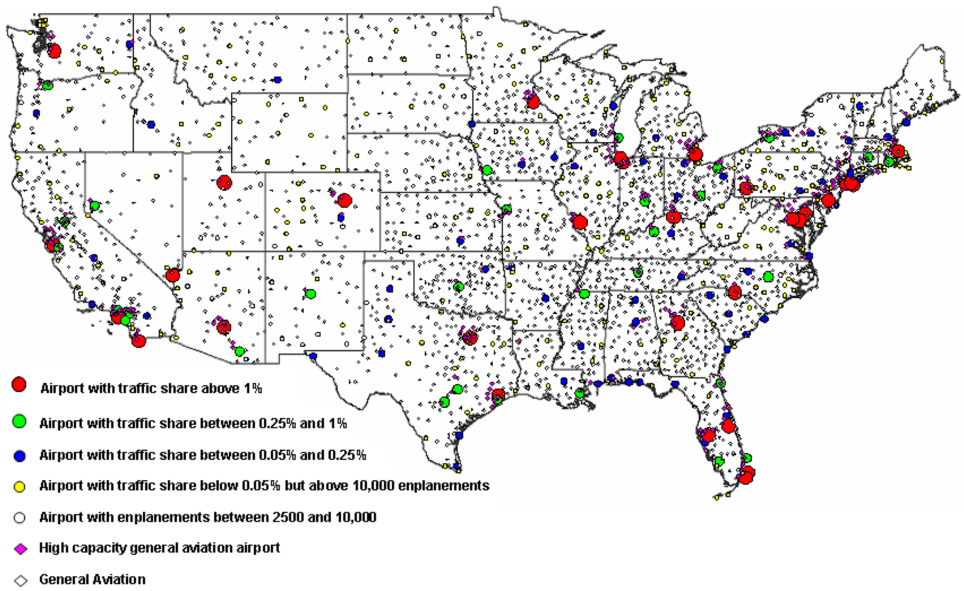

Figure 24: Geographical distribution of airports (by type and size) in the United States in 2004[1]

Higher concentrations of airports are observed in the North-East and in California. This concentration of airports is generally correlated with the distribution of population. Due to the lack of land availability in metropolitan regions and other factors such as pressure and opposition from local residents to the construction of new airports (i.e. for both land right-of-use and environmental concerns), the current set of airports is not likely to significantly expand in the United States over the coming decades. The network of U.S. public and certificated[2] airports has not expanded in the United States during the last decades as Figure 25 shows. Between 1980 and 1999, the average net loss of

[1] Data source: FAA, National Plan of Integrated Airport Systems (NPIAS) Reports, 2005-2009 NPIAS Report, Complete list of NPIAS Airports, available at: http://www.faa.gov/airports_airtraffic/airports/planning_capacity/npias/reports/, last accessed: January 2008.

[2] Note: Federal Regulation 49 CFR Part 139 prescribes the rules governing the certifications and operation of land airports which serve any scheduled or unscheduled passenger operation of an air carrier that is conducted with an aircraft having a seating capacity of more than 30 passengers. Any airport serving schedules or unscheduled air carrier operations must have a current airport operating certification. Source: Federal Aviation Regulations Part 139 Airport Certification, available at : http://www.faa.gov/airports_airtraffic/airports/airport_safety/part139_cert/, last accessed ; April 2008.

certificated airports reached 4 airports per year, accounting for an annual rate of -0.6%. In the case of public airports, after a significant growth in the early 1980s, the national set of public airports was diminished by an average of 36 airports per year.

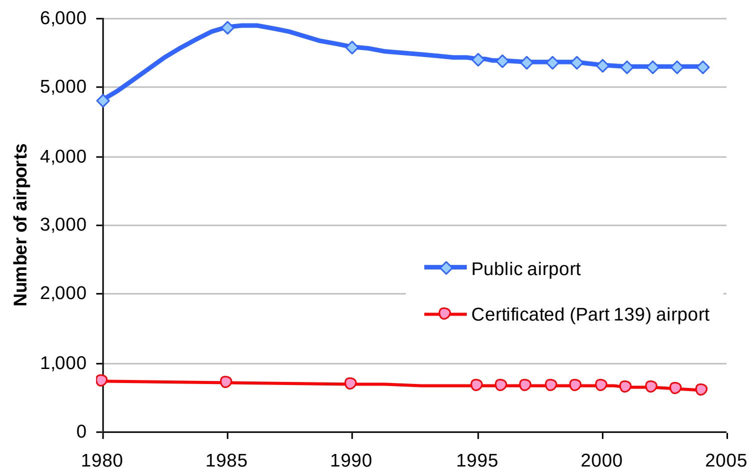

Figure 25: Historical evolution of the number of public airports and certificated airports in the United States between 1980 and 2004[1]

While the number of airports in the United States is fairly significant (while not increasing), only a small fraction of these airports are utilized for commercial operations. Using historical records of enplanements from the FAA Terminal Area Forecasts database[2] airport traffic shares were computed for each of the 2715 airports for which traffic is reported (i.e. in the FAA National Plan for Integrated Airport System NPIAS). Figure 26 shows the cumulative distribution of traffic share of airports ranked by decreasing importance. Only 31 airports handle 70% of the overall U.S. passenger traffic and 90 % of the traffic is handled by 70 airports.

[1] Data source: Bureau of Transportation Statistics (BTS), National Transportation Statistics, Statistical Abstracts available at: http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_01_32.html), last accessed: December 2004.
[2] Data source: Federal Aviation Administration, "Terminal Area Forecasts, (historical records)", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: 2004.

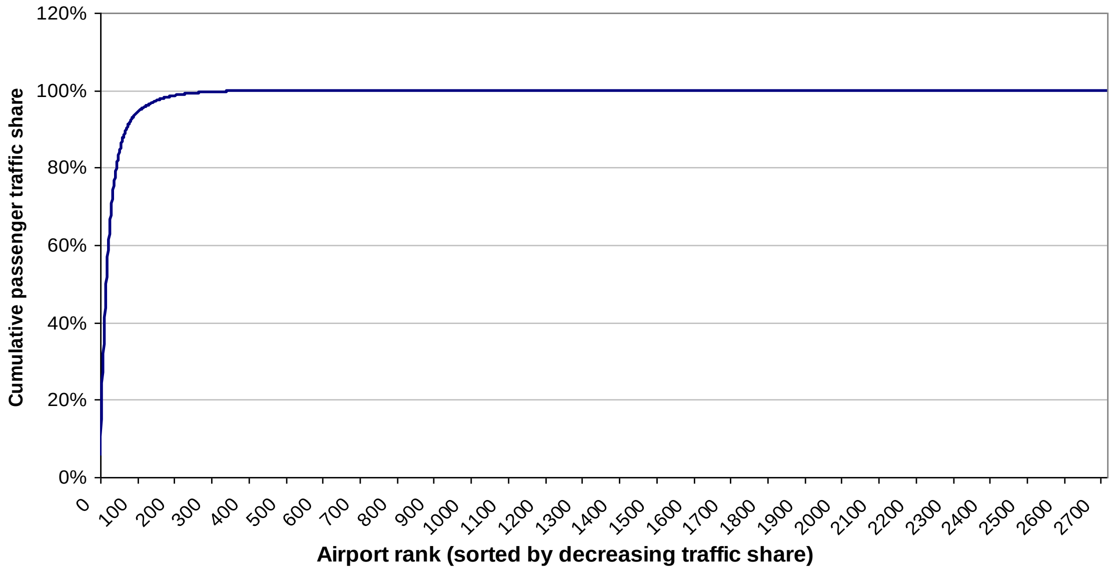

Figure 26: Lorenz curve of airport traffic share in the United States

2.3.4 Airport congestion problem and delays

As shown on Figure 12, delays are the result of congestion (i.e. high ratio of the demand rate divided by the capacity[1]) at some airports in the air transportation system. Figure 27 shows the monthly delays in the United States from 1995 to 2008 with its 12 month moving average. The typical annual pattern of delays is usually characterized by relatively low level of delays from January to April. The increase of the operation counts during the summer forces delays to increase (due to fixed short term capacity of the system). Peaks of delays typically appear in June, July and August. After the summer, delays generally decrease gradually.

[1] Note: Airports are highly dynamic queuing systems. High ratios of the demand rate divided by the capacity are not necessarily observed throughout the day.

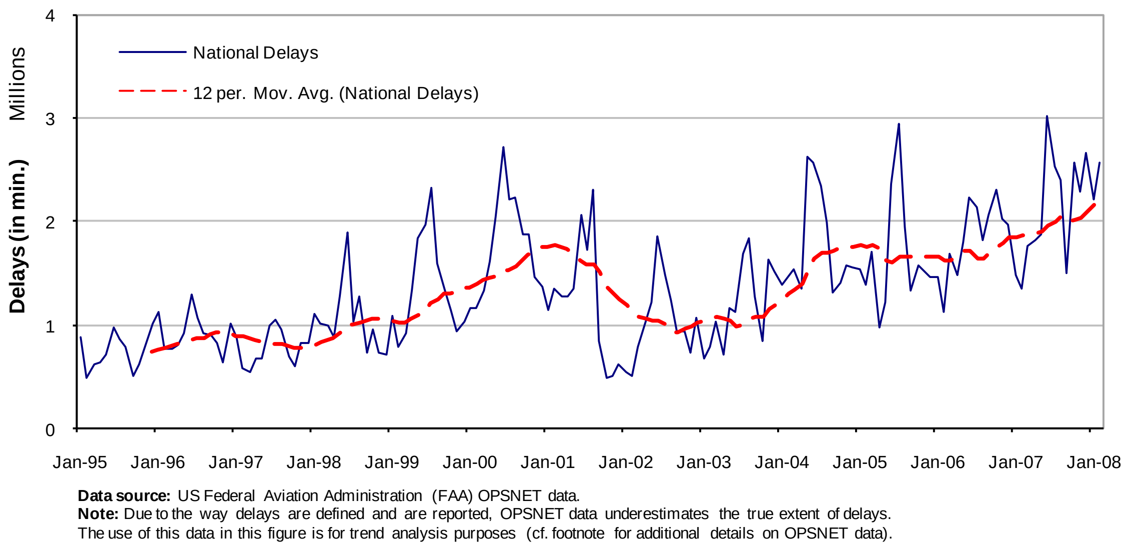

Figure 27: Monthly delays in the United States from 1995 to 2008[1]

The 12 month moving average clearly highlights the general trend of increasing delays until 2001 (Figure 27). Delays reached a peak in June 2000. However, unlike previous years, in 2000, delays did not drop significantly at the end of the summer and remained at high levels until November. By the first quarter of 2001, the beginning of an economic recession started to have an impact on traffic. As traffic decreased, delays did not persist. With the major reduction in number of flights after September 2001, pressure was relieved from the system and delays reached a record low in October. The recession that started in early 2001 coupled with the impacts of Sept. 11 events, relieved some pressure on the system. In October 2001, delays were at their lowest level since May

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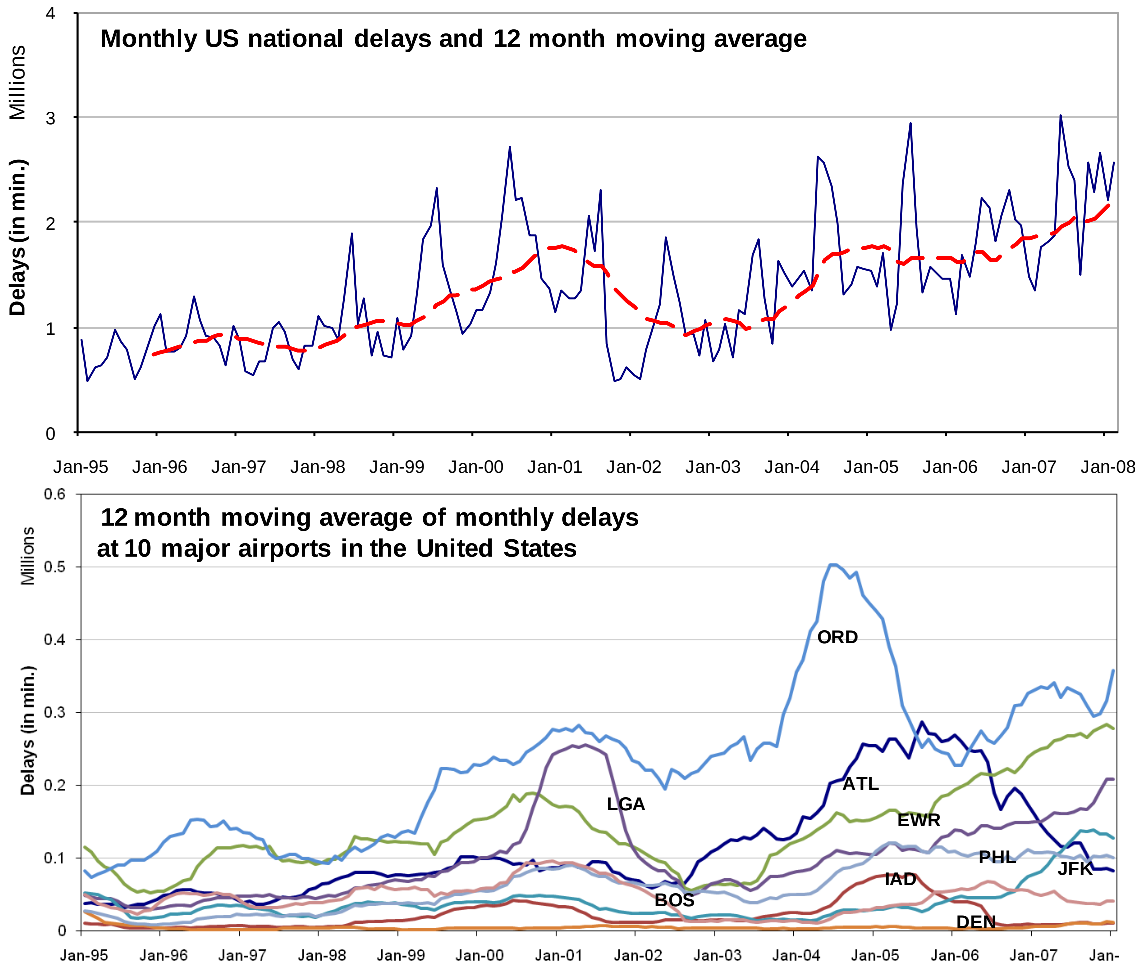
[1] Data source: US Federal Aviation Administration (FAA), OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: April 2008. Note: For the purpose of delay trend analyses and comparative analyses of airport delays (i.e. location of delays), OPSNET data was used. It must be noted that OPSNET data reports underestimate the true extent of delays (El Alj, 2003). OPSNET data is maintained by the FAA through Air Route Traffic Control Centers (ARTCC) reports. Only flights with delays of 15 minutes or more are reported. A reportable delay recorded in OPSNET is defined in FAA Order 7210.55B as, "Delays to Instrument Flight Rules (IFR) traffic of 15 minutes or more, experienced by individual flights, which result from the ATC system detaining an aircraft at the gate, short of the runway, on the runway, on a taxiway, and/or in a holding configuration anywhere en route shall be reported." Such delays include delays due to weather conditions at airports and en route, FAA and non-FAA equipment malfunctions, the volume of traffic at an airport, reduction to runway capacity, and other factors. In addition, OPSNET does not report flight delays due to international causes (e.g. flights delayed at a center outside the United States). Airline Service Quality Performance (ASQP) is a source of data that provides a more accurate estimate of delays (i.e. percentage of operations delayed). However, time series analyses are limited with this dataset, since data is only reported after 1999 for major airports and 2004 for smaller airports (i.e. secondary airports).

1995. Even though delays were not an issue after the end of 2001, concerns reappeared late 2003. In 2004, delays reached record levels again. While the general increase in traffic load on the system is responsible for part of the high level of delays observed across the national airspace system, this situation is also caused by localized problems at some key airports. These airports generate high levels of delays that propagate throughout the air transportation network. Figure 28 shows the historical evolution of delays at the top 10 airports in the United States from 1995 to 2008.



Data source: US Federal Aviation Administration (FAA) OPSNET data.
Note: Due to the way delays are defined and are reported, OPSNET data underestimates the true extent of delays.
The use of this data in this figure is for trend analysis purposes (cf. footnote for additional details on OPSNET data).

Figure 28: Twelve month moving average of monthly delays at 10 airports in the United States from 1995 to 2008[1]

[1] Data source: FAA OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: March 2008.

As shown on Figure 28, in 2000, New York/LaGuardia (LGA) exhibited a record level of delays. This sudden increase of demand at New York/LaGuardia was the result of the adoption by Congress of the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century (AIR-21), enacted on April 5th 2000. This act allowed an exemption from the High-Density Rule (HDR)[1] limits for flights performed with aircraft of 70 or fewer seats, between New York/LaGuardia and "small hub and non-hub airports"[2]. Slot restrictions were in place to constrain the scheduling behavior of airlines by capping the total number of operations that can be performed at the airport. Without the restrictions, airlines started to add scheduled operations above the airport capacity, which resulted in an over utilization of the airport that materialized into record high volume of delays. By December, the FAA requested airlines to cut a fraction of their operations. Demand dropped between November and December 2000. As a result delays decreased significantly between December 2000 and January 2001.

Because airports are part of an integrated network, the irregular behavior of one airport is propagated throughout the network and affects other parts of the network. This was the case in 2000 when the propagation of delays from New York/LaGuardia to the rest of the network resulted in this early nationwide crisis. The contribution of New York/LaGuardia (accounting for 14% of the national delays in 2000) to the national level delays is clearly visible on Figure 28.

In 2003, Chicago/O'Hare (ORD) recorded a significant increase in delays. These volumes of delays remained at high levels through December 2003 and January 2004. During the three months from November 2003 to January 2004, delays at Chicago/O'Hare represented 40% of the total delays at the national level. Similarly with New York/LaGuardia in 2000, the cause of the delays at Chicago/O'Hare remains capacity shortfall due to the over scheduling behavior of airlines and the limited capacity of the airport. For the 07:00 to 21:59 operation period, demand far exceeded the capacity

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[1] As of 2005, the High-Density Rules (14 CFR Part 93) designate four airports as slot-controlled airports. Those airports are Chicago/O'Hare (ORD), New York/LaGuardia (LGA) and New York/Kennedy (JFK), and Washington/Reagan (DCA). It was enacted in 1968 (14 CFR part 93, Subpart K, 33 FR 17896; December 3, 1968). Originally, it was scheduled to remain effective until the end of 1969. It was however extended to October 25, 1970. In 1973, it was extended indefinitely.

[2] The FAA defines "Small Hub airports" as airports that handle between 0.25% and 0.05% of the national volume of enplaned passengers. "Non Hub airports" are smaller than "Small Hub airports" and handle less than 0.25% of the national passenger traffic and more than 10,000 enplaned passengers.

of the airport. In an effort to control this capacity crisis, the U.S. Department of Transportation requested that United Airlines and American Airlines cut 62 (5%) of their flights during the peak-hour period. As delays remained at high levels in March, another reduction was necessary. On April 21st 2004 the FAA asked United and American to reduce their scheduled operations by 29 departures and 17 arrivals scheduled between 12:00 and 20:00. This measure was supposed to be valid from June 10 to October 30 in order to face the expected summer congestion problem. The record high delays and the recent decisions from the FAA to cut operations highlight the existence of a capacity crisis at this airport. In addition, the cuts of operations clearly show that demand is not met at this airport.

In 2007, record levels of delays were recorded compared to previous years. As shown on Figure 28, the New York airports are responsible for a significant share of these delays. Delays at New York/Kennedy (JFK) increased year over year by more than 75% between 2005 and 2007. Similar trend was observed at New York/Newark (EWR). Delays have also been resurging at New York/LaGuardia (LGA) while remaining below 2000 levels.

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CHAPTER 3

RELATED WORK

3.1 Introduction

This chapter reviews the literature on theories and studies that support the different components of this research. Given the overarching motivation and topic of this research (i.e. scalability of the air transportation system), literature on the analysis and the measurement of the scalability of systems was reviewed. As presented in Chapter 4, the choice of a multi-level approach motivated the need for a high level analysis of the structure and the scalability of the air transportation system. The literature on network analyses and theories proved to be useful in providing a starting point for this high level analysis of the structure of the air transportation system. Finally, given the focus of this research on the development of multi-airport systems as a key scaling mechanism specific literature on multi-airports systems was reviewed.

3.2 Literature Review on the Scalability of Systems

The scale of a system is defined as the size of a system (NECSI, 2008). Other definitions of scale can be found in the literature including; the level of observation or description of a system, which can also be referred to as scale of observation[1]. For the purpose of this thesis, the first definition will be used to refer to scale (i.e. the size of a system).

Based on the first definition of scale, scalability is defined as (1) the ability of a system, network or process to change its scale in order to meet growing volumes of demand, (2) the ability of a system to maintain its performance (i.e. relative performance)

[1] Note: For the purpose of this thesis and because of the use of multi-scale analysis in the later part of this document, the second definition of scale (i.e. the level of observation or description of a system) will be referred to as "level of observation of a system" or more simply "level", hence referring to "multi-level analysis".

and function, and retain all its desired properties when its scale is increased greatly without having a corresponding increase in the system's complexity[1].

3.2.1 Scalability of "simple" systems

Scalability in the context of simple systems (or product systems), also referred to as scaling laws, has been studied in detail (Whitney, 2006). Scaling laws describe for instance the relationship between the variation of the dimensions of physical systems (e.g. length, width, height, diameters) and the variation of a measurement of output (e.g. flow, etc.). These scaling laws are practical for deterministic and simple systems that can be described using physics based equations. However, due to the complexity and the emergent behaviors that characterize engineering systems these scaling laws are not necessarily applicable to describe these systems.

3.2.2 Scalability of complex systems

Scalability has been studied in a wide range of contexts; video imaging, mobile computing simulation, data mining, telecommunications, software processes but with most emphasis in distributed parallel computing systems (Duboc, et al., 2006).

Scalability is also a key property of telecommunication systems. These systems typically have to serve increasing number of geographically distributed customers through the increase of hardware distributed over the network (Bondi, 2000). The concept of scalability is also used in telecommunication engineering and computer science to describe how routing protocols scale and are affected by network size.

Scalability can be measured along several dimensions (Bondi, 2000) such as; load scalability (i.e. expand capacity to satisfy higher loads), geographic scalability (i.e. ability of the system to scale regardless of the geographic locations of the resources).

There are significant differences between the nature of air transportation (i.e. transport system) and telecommunications (i.e. information system) that limit the direct applicability of this literature. The geographical characteristics of the path (i.e. location of connecting nodes) matter in the case of the air transportation system whereas in the case

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[1] Note: The first definition is a general definition while this second definition is a more restrictive version of the definition.

of information systems a message or a packet of information can be routed through multiple paths.

3.2.3 Scalability of the air transportation system

The limits to the scale of the air transportation system and network were explored for un-weighted networks (i.e. topology of the network without regard of the frequency on the arcs of the network) by Barrat et al. (2003). They posed the hypothesis that spatial constraints (i.e. the number of destination reachable from airport nodes in the network) were a factor constraining the scale of the network (Barrat, et al., 2003).

3.3 Scale-free and Scalable Networks: Theory and Models

Given that the air transportation system is a large scale, complex system (i.e. composed of thousands of subsystems and parts interconnected) it can be described and represented using network abstractions. A body of literature on scale-free network theory, scalable networks and network evolution was reviewed and studied as a starting point for the analysis.

3.3.1 General theory of complex networks

The origin of the study of networks can be traced back to Euler's Konigsberg bridges problem in 1736. Since that time, network theory has evolved with the development of strong mathematical bases for characterizing networks, optimizing their structure and their flows (i.e. mostly from the operations research community). In the 1950s with the work of Erdos and Renyi, networks were considered to be random; characterized by graphs in which the arcs are distributed randomly between the nodes (Erdos, et al., 1959). Work by Rapoport on random biased networks (Rapoport, 1957) then Stanley Milgram's work on the small world problem initiated a paradigm shift in network theory. In 1998, Watts and Strogatz proposed a model of the small-world network (Watts, et al., 1998).

The analysis of the topology of large scale networks, in the late 1990s, such as the World Wide Web, led to the discovery of a new family of networks called scale-free networks that resulted in significant interest in network topology analysis (Watts, et al., 1998). This general interest in better understanding the topology of networks was followed by interest in establishing the relationship between their structure and the properties of the systems that were represented by these networks. The general objective was that by knowing how the structure of the networks relates to the properties of the systems, one would be able to provide prescriptive directions as to how to better design these systems.

3.3.2 Scale-free networks

A network is called scale-free if its degree distribution (i.e. the probability that a node selected uniformly at random has a certain degree) follows a particular mathematical function called a power law. The degree of a node is defined as the number of arcs (i.e. links) that are connected to other nodes in the network. In the context of air transportation, the degree of a node is the number of routes connecting one airport to other airports in the network.

The power law distribution of the degree sequence can be interpreted by the observation that a large fraction of the nodes are connected to only a few other nodes (i.e. small degree nodes) and a very small fraction of the nodes are highly connected to other nodes (i.e. large degree nodes).

Figure 29 shows (on the left side) a random network in which the connections between the nodes are randomly distributed and (on the right side) a scale-free network.

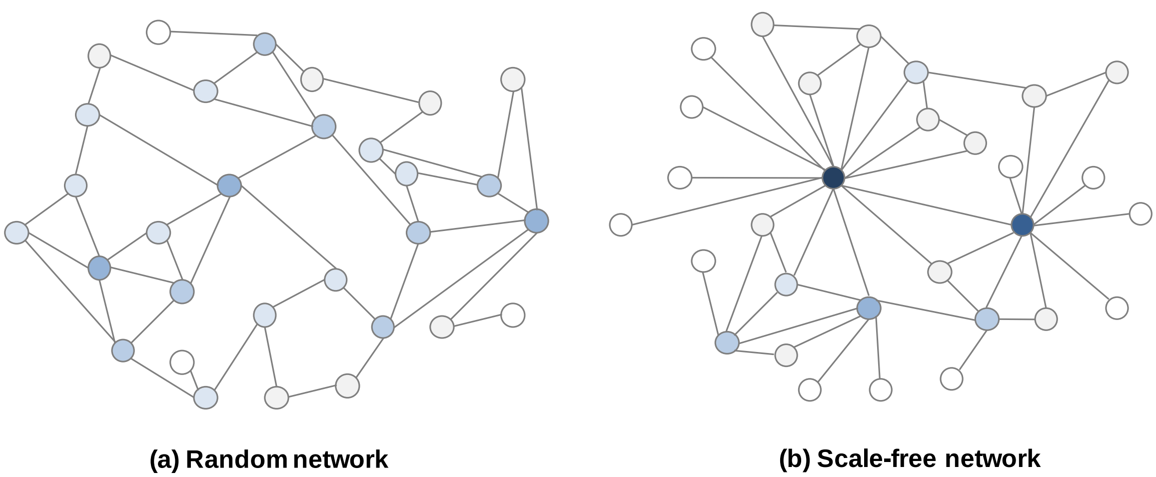

Figure 29: Conceptual representation of a random network (a) and a scale-free network (b)

The structure of scale-free networks is also independent of the size of the network (i.e. number of nodes in the network). The power law that characterizes the structure of the network implies that the degree distribution of these networks has no characteristic scale (i.e. concept similar to fractal theories and representations). A network that is scale-free will have the same properties no matter what the number of its nodes is. This notion is also referred to as scale invariance.

Figure 30 illustrates the case of the internet, in 1999. This network was identified as a scale-free network (Newman, 2003).

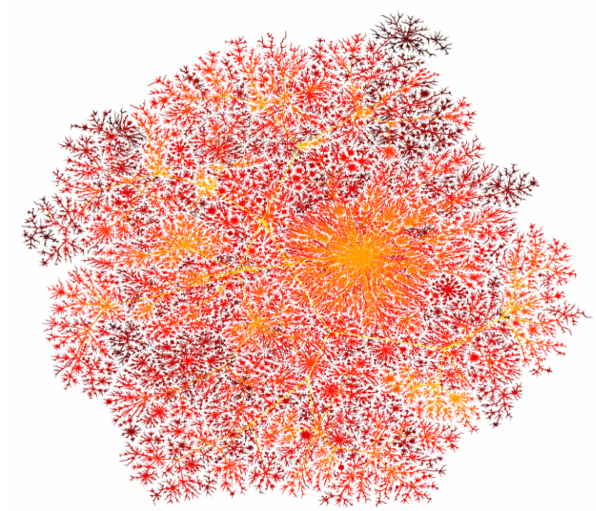

Figure 30: Illustration of a scale-free network (i.e. internet in 1999) [Source: (Cheswick, 2003)]

As mentioned above, a network is defined as scale-free if its degree distribution follows a negative power law degree distribution (Equation 1).

Equation 1: $$p(k) \propto k^{\gamma}$$

Figure 31 shows the negative power law (i.e. $\gamma<0$) plotted with a linear-linear axis scales.

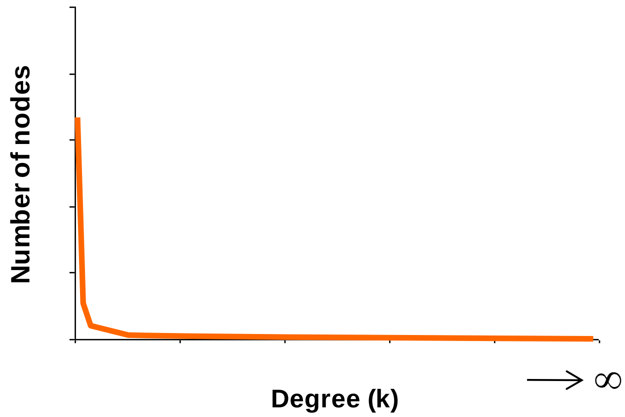

Figure 31: Conceptual network degree distribution (linear-linear plot)

Because of the nature of the networks that are represented by negative power laws, there are very few nodes (i.e. data points used to construct the degree distribution) that exhibit high degrees. As a result, it is inherently hard to identify power law in the upper part of the degree distribution. For this reason, a cumulative degree distribution is often constructed. Equation 2 represents the cumulative degree distribution. Negative power law distributions can be easily identified on log-log plot since they are characterized by a linear function as shown on Figure 33.

Equation 2: $$p(k > K) = \int_K^{\infty} k^{\gamma} dk \propto k^{\gamma - 1}$$

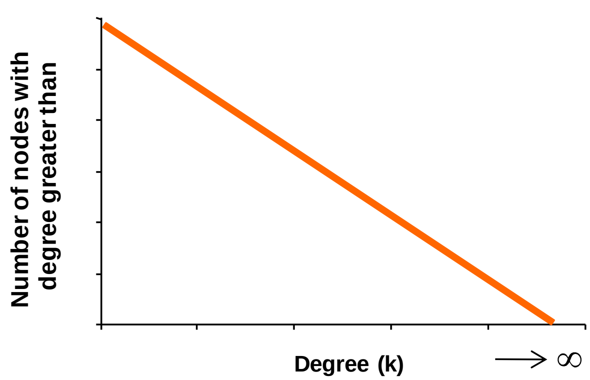

Figure 32: Conceptual network degree cumulative distribution (log-log plot)

Scale-free networks (i.e. networks with negative power law distributions) have been studied extensively and many large scale complex systems have been characterized by scale-free network structure; Internet (Newman, 2003), (Dorogovstev, et al., 2003), (Chen, et al., 2002), world wide web (Newman, 2003), (Faloutsos, et al., 1999), (Albert, et al., 1999), (Barabasi, et al., 2000), (Border, et al., 2000), electric power grid (Barabasi, et al., 2000), scheduled air transportation network (Guimera, et al., 2003). Li et al. proposed an initial theory of scale-free networks (Li, et al., 2005).

Scale-free refers to a characteristic of the structure of the network. Given the definition of scalability; the ability of a system, network or process to change its scale in order to meet growing volumes of demand, scalability refers to the evolutionary property of the network. Figure 33 represents the example of the scale-free distribution of a network that is also scalable. As the number and degree of the nodes in the network increase the power law distribution moves to the right, to higher degrees.

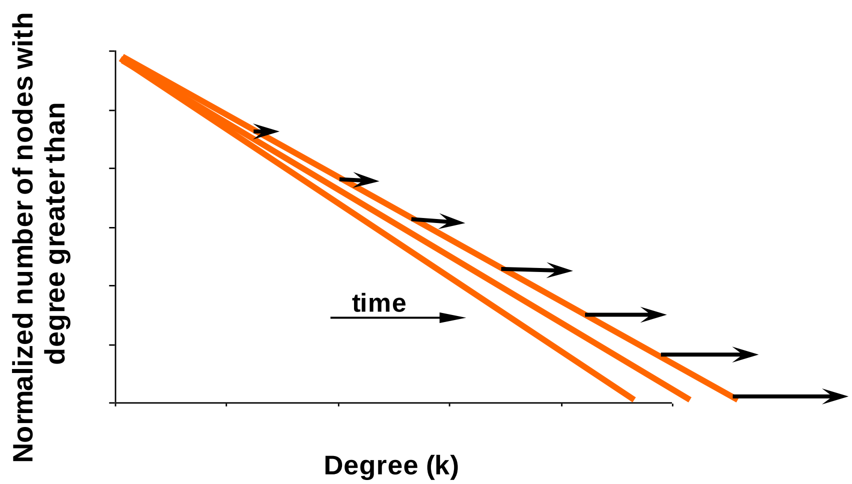

Figure 33: Degree distributions of a scalable scale-free network (log-log plot)

3.3.3 Evolution of complex networks: Underlying fundamental mechanisms and models

Historically, network theory focused on the description and characterization of the structure of networks. As the structure of networks was better understood, their evolution was explored and characterized (Barabasi, et al., 1999), (Newman, 2003), (Dorogovstev, et al., 2003).

Barabasi and Albert proposed a general and simple network growth model (Barabasi, et al., 1999). The underlying growth mechanism for this model was based on the notion of preferential attachment of nodes. In this process, nodes grow proportionally to the attractiveness of a node, which is proportional to its size in the network. As shown on Equation 3, the probability (Π) of a node connecting to another node i depends on the degree k_i of node i.

Equation 3:
$$\Pi(k_i) = \frac{k_i}{\sum_{i \in N} k_i} \quad \forall i \in N$$

Barabasi et al. demonstrated that networks that grow according to this underlying dynamic result in networks with power law degree distribution (Barabasi, et al., 1999). A corollary to the preferential attachment process theorem, states that the normalized rate of growth of nodes in the network is proportional to the relative size of nodes in the network (Equation 4).

Equation 4:
$$\frac{\frac{\partial w_i}{\partial t}}{\sum_{i \in N} \frac{\partial w_i}{\partial t}} \propto \frac{w_i}{\sum_{i \in N} w_i} \quad \forall i \in N$$

Other network growth models were explored of which networks that grow based on sub-linear preferential attachment dynamics (Krapivsky, et al., 2001). Sub-linear refers to the differential rate of growth of nodes depending on their size in the network. In a sub-linear growth model, large nodes grow slower than they would under a linear growth model (i.e. Barabasi-Albert model). Conversely, in a super-linear growth model, large nodes grow faster than they would under a linear growth model.

3.3.4 Network analysis in the context of the air transportation system

Given the nature and function of the air transportation system (i.e. involving flows of passenger and cargo from point-to-point), several analyses of the structure of the air transportation network have been performed. Guimera et al. performed a cross-sectional analysis of the global structure of the worldwide air transportation network (Guimera, et al., 2003). The analysis was based on one week of OAG data[1] from November 1st to 7th 2000. They found that the worldwide air transportation network is a scale-free small-world network for a limited range of degrees of nodes (i.e. airports), disregarding the approximately top 2% of the nodes (i.e. accounting for approximately 730 airports). They also found that the most connected cities are not necessarily the most central[2]. They demonstrated that these anomalies arise because of the multi-community structure of the network resulting from geographical constraints and geopolitical considerations.

Motivated by systems-of-systems theory, Han and DeLaurentis analyzed the structure of the U.S. commercial air transportation level based on Bureau of Transportation Statistics (BTS) data from 2004 (Han, et al., 2006). They found that degree distributions are suited as a design tool in preliminary design of network topologies, and that centralized networks are more efficient at handling uniformly distributed demand through shortest paths than distributed networks.

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[1] Note: Official Airline Guide (OAG) is a source of scheduled airline flight information.

[2] Note: The centrality of a node is defined the number of shortest paths (among the set of shortest paths between any possible combination of two nodes in the network) passing through this node.

3.4 Literature Review on Multi-Airport Systems

Given the focus of this research on the development of multi-airport systems as a scaling mechanism in the air transportation system, specific literature on multi-airport systems was reviewed[1].

In the past, multi-airport systems have been studied from different perspectives; (1) planning and development to guide airport developer and operator decisions, (2) passenger traffic distribution within a set of airports using econometric models to predict where demand and passenger traffic will materialize.

3.4.1 Definitions

de Neufville and Odoni (2003) define a multi-airport system as; a set of significant airports that serve commercial transport in a metropolitan region, without regard to ownership or political control of the individual airports.

Other definitions of multi-airport systems can refer to a set of airports managed by one individual operator or authority (ACI, 2002).

Multi-airport systems have also been categorized into several types; (1) *mega polis* that are located in major urban concentrations handling more than 50 million passengers per year and having more than 5 million inhabitants, (2) *regional territories* that are less concentrated areas, than mega polis, that may possess large hinterlands but smoother urban settlements and (3) *archipelago* that are territories with land mobility constraints that result in a forced network of airports forming an airport system (i.e. set of distributed airports) (Garriga, 2003).

3.4.2 Development of multi-airport systems

The strategic planning mistakes that were made in the development of some multi-airport systems (e.g. Montreal/Mirabel, Washington/Dulles), motivate the need for a dynamic strategy approach for developing multi-airport systems (de Neufville, 1995). Patterns of concentration of airline traffic (i.e. dynamics of the competition amongst airlines and airports) and the uncertainty of future materialization of passenger traffic in a

[1] This work also builds on previous work by Bonnefoy and Hansman that focused on the emergence of secondary airports and the development of multi-airport systems in the United States (Bonnefoy et al. 2005).

regional competitive environment also motivate this dynamic strategy approach. With this approach, investments in airports are performed in an incremental and flexible manner to adjust the infrastructure supply more closely to demand needs (de Neufville, 1995).

The development of secondary airports was also influenced by the emergence and growth of no-frills airlines (de Neufville, 2004). The impact of no-frills airlines was found to supplements the number of originating passengers (e.g. identified around 10 to 12 million passenger per year (de Neufville, 1995)), that had traditionally been the significant factor that promoted the establishment of viable multi-airport systems.

In parallel to the development of low-cost airlines, the development of low-cost airports has also been observed (de Neufville, 2007). The development of low-cost airports (i.e. tailoring their services and charges to low-cost carriers) changes the airport planning and design paradigms. Low-cost carriers have specific needs (i.e. cheaper airport terminals with different internal configurations) compared to the needs of legacy carriers. The different needs by different types of airlines (i.e. low-cost airlines versus legacy airlines), the competition dynamics between these segments of the airline industry and the resulting volatility of traffic further motivates the need for a dynamic strategy approach of airports (de Neufville, 2007).

3.4.3 Modeling passenger traffic distribution in multi-airport systems

Multi-airport systems have also been studied through the analysis and modeling of passenger traffic distribution within a set of airports. These studies used predominantly econometric models to understand and predict where demand and passenger traffic will materialize.

Ishii et al. (2005) used a logit model to measure the impact of airport and airline supply characteristics on the air travel choices of passengers traveling between the airports in the San Francisco and Los Angeles metropolitan regions (Ishii, et al., 2005). This type of model relies on travel attributes (e.g. airport access time, airport delay, flight frequency, availability of particular airport-airline combinations) and attempts to explain the passenger travel choices and passenger traffic distribution among airports in the metropolitan regions. This study found that changes in access times affect travel choices more than changes in travel delays, and that the preferred airport differs by passenger type (Ishii, et al., 2005).

Hansen and Du investigated and modeled traffic allocation between multiple airports serving one region using a positive feedback model that assumed that service attributes were endogenous to the system, and directly related to airport traffic volume. This study suggested that the more traffic an airport has, the more attractive it becomes. This model was applied to the airports in the San Francisco Bay Area (i.e. San Francisco/Intl, San Francisco/Oakland, and San Francisco/San Jose). The model was also calibrated to predict the market share of San Francisco/Buchanan Field, located in Concord, Contra Costa County, 27 nautical miles northeast of San Francisco/Intl. The model predicted a traffic shares ranging from 10% to 25% of the regional traffic for this airport. However, the actual market share (i.e. at the time of the study) did not exceed 3%. It was found that factors such as airport management behaviors and service availability awareness could explain this difference. This observation showed the limitations of the model to established airports that are committed to providing commercial services (Hansen, et al., 1993).

CHAPTER 4

APPROACH

4.1 Overview of the Approach

Given the motivation of the research to investigate the mechanisms by which the air transportation system scaled to meet demand in the past and will do so in the future and the fact that the air transportation system is large-scale, adaptive, socio-technical system, an approach based on multi-level[1] and holistic analyses was taken.

4.1.1 Multi-level analysis of the system

As shown on Figure 34, the air transportation system can be decomposed into several components that can be analyzed at different levels of observation. At the highest level (i.e. the international level), the air transportation system is described in its whole. One level down, differences start to appear at the national level (i.e. individual country level). Another level down, the system can be decomposed and analyzed at the regional level (e.g. multi-airport systems serving a metropolitan region). Finally, the regional level component of the system can be further decomposed into individual airports (i.e. local level). While the system can be further decomposed into finer grain elements (i.e. runways, etc.), for the purpose and relevance of this research the decomposition of the system was stopped at the airport level.

[1] Note: For the purpose of this research and not to confuse the reader between the two definitions of "scale" (i.e. (1) the size of a system, (2) the level of observation or description of a system), the concept of multi-scale analysis (i.e. analysis of the different levels of precision of observation or description of a system) will be referred to as "multi-level analysis".

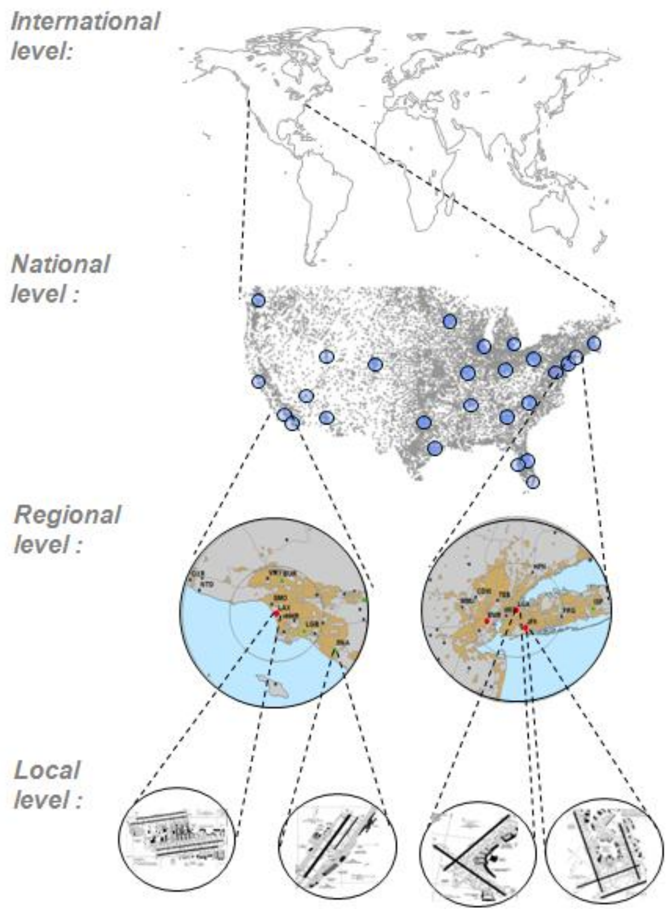

Figure 34: Conceptual multi-level representation of the air transportation system

The motivation of this research was to investigate the scalability of the air transportation system (i.e. ability of the air transportation system to scale to meet growing volumes of demand). Given that "scalability" is a general system property; its analysis requires that the starting point of the approach be the highest levels of abstraction of the air transportation system (i.e. international level and national level).

Given the fundamental network nature of the air transportation system, a network analysis using theories of scale free and scalable networks was performed. This step composed the first step of the approach. This analysis motivated a more detailed analysis of the air transportation system at the regional level (i.e. understanding of the configurations and evolution of multi-airport systems) and then at the local level (i.e. characteristics and dynamics governing the evolution of individual airports). The analysis of the system at the regional level (i.e. metropolitan regions) and the local level (i.e.

airports) was performed through a multiple-case study analysis described in greater detail in section 4.2.

The multiple-case study analysis provided detailed understanding of the dynamics that govern the system and the factors that influence these dynamics at the regional level and the local levels. This phase of the approach was instrumental in explaining the differences that were observed at the international level (i.e. differences in the occurrence of patterns of evolution of multi-airport systems between different countries).

4.1.2 Holistic view of the system

The dynamics that affect the evolution of the air transportation system and more specifically the development of multi-airport systems and airports are influenced by a wide array of factors. These range from ***(1) technical factors*** (e.g. compatibility of aircraft requirements and airport infrastructure capabilities), ***(2) management and regulatory factors*** (e.g. airline dynamics, policies to restrict the use of an airport to certain operators) and ***(3) social factors*** (e.g. distribution of population around airports, opposition to airport development by local communities). This multi-factor nature of the problem favored the pursuit of an Engineering Systems (ES) approach. As described in Figure 35, Engineering Systems exhibit a combination of technical, management and social components.

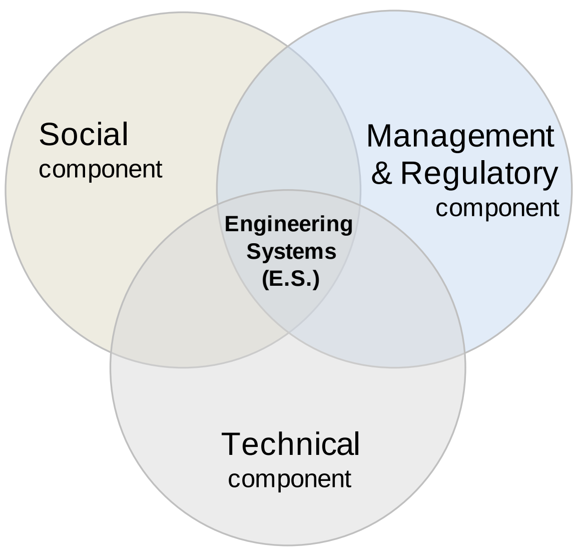

Figure 35: Conceptual representation of multi-faceted Engineering Systems (ES)

The objective of this type of approach is to perform a systematic analysis of the system under investigation -multi-airport systems in this case- in order to identify the fundamental mechanisms that govern the evolution of the system across the set of three components (i.e. technical, management and social components). From this understanding, the objective is to then derive insights as to how to better design, operate and manage the system.

4.2 Detailed Approach

4.2.1 Network theory based investigation of the scalability of the air transportation system

Because the air transportation system is fundamentally a network system (composed of thousands of interconnected subsystems and parts) it can be described and represented using abstractions and tools from network theory. Recent theories of scale-free and scalable networks presented in the literature sections were used as a starting point for the analysis.

In order to analyze the structure of the air transport network in the United States, a cross-sectional analysis (i.e. analysis of the structure of the network at one point in time) was performed using aircraft traffic data from the Federal Aviation Administration's (FAA) Enhanced Traffic Management System (ETMS). Details on the methodology used to conduct this analysis are presented in section 5.1.1)

This cross-sectional analysis of the air transportation network was followed by a time series analysis of the network. This analysis was based on historical data from the FAA Terminal Area Forecast database[1] that covered a time period ranging from 1976 to 2005. Details on the methodology used to conduct this analysis are presented in section 5.2.1). Both of these analyses involved the decomposition of the air transportation network into different levels of observations presented in Figure 34 through analyses of the network, first at the airport level (i.e. nodes defined as airports) and second at the regional level (i.e. nodes defined as multi-airport systems and airports).

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[1] Data source: Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: February 2007.

4.2.2 Multiple-case study analysis of multi-airport systems

Based on social science research principles (Yin, 1994), a multiple-case study analysis was performed (i.e. analysis of the system at the regional and airport levels). Both quantitative and qualitative evidence, originating from a wide range of sources were gathered to support the multiple-case study analysis.

The first phase of the case study approach involved the definition of the boundaries of the system (i.e. multi-airport systems). In order to identify multi-airport systems, a geographical cluster analysis was performed to identify airports located in the vicinity of each other and that had significant passenger traffic. This analysis resulted in the identification a set of multi-airport systems that formed the basis for the multiple-case study analysis.

While some case study analysis protocols select a sample of cases among a larger set of available cases, for the purpose of this research the entire set of identified cases of multi-airport systems was examined. For each case (i.e. one case being defined as one multi-airport system), the set of primary and secondary airports was identified. A geographical analysis was performed to evaluate the location of each airport relative to the center of the metropolitan area (i.e. primary city) and secondary basins of population. An analysis of the historical evolution of traffic was also performed using passenger traffic data. Using a large set of sources (i.e. airport websites, airport authority annual reports and websites, industry and trade group publications), an historical analysis of the key events that affected the evolution of individual airports was performed.

4.2.3 Development of a feedback model

Given the insights into the past and future role of multi-airport systems from the network analyses, a more detailed analysis of these systems and the dynamics that govern them was performed. Hypotheses on the dynamics that were governing these systems and the factors that influenced these dynamics were formed. These hypotheses were cast into a feedback model. This model was iteratively refined using the multiple-case study analysis of multi-airport systems.

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CHAPTER 5

NETWORK THEORY BASED INVESTIGATION OF THE SCALABILITY OF THE AIR TRANSPORTATION SYSTEM

Because the air transportation system is fundamentally a network it can be described and represented using abstractions and tools from network theory. In order to characterize and investigate the evolution of the air transportation networks, the structure of air transportation networks were analyzed using actual traffic data.

5.1 Cross-Sectional Analysis of the U.S. Air Transportation Network

5.1.1 Data sources and methodology

The network of interest for this research is the flight (i.e. aircraft flow) network. In this network the nodes represent airports and the arcs are non-stop origin-destination routes between airports. As represented on Figure 12 (cf. Chapter 2), the air transportation system is composed of a set of layers that can be represented as networks. For the purpose of this research, the flight/aircraft flow network is the layer of most interest since the airport congestion problem that was described in Chapter 1 involves aircraft traffic and airport throughput (i.e. airport capacity).

In order to analyze the structure of the current air transport network in the United States, a cross-sectional analysis (i.e. analysis of the structure of the network at one point in time) was performed using aircraft traffic data from the Federal Aviation Administration's (FAA) Enhanced Traffic Management System (ETMS). For each flight, this database provided the aircraft type, the airports of departure and arrival, the aircraft position (latitude, longitude and altitude) and speed information.

For the extraction of the network structural information, a data set of 365 days of traffic was analyzed (from October 1st 2004 to September 30th 2005). In addition to the detailed ETMS flight database, a database of civil airplanes corresponding to 869 ETMS aircraft codes was used. The ETMS airport database was crossed with the FAA Form 5010 airport database[1] that provided additional airport information such as runway characteristics (i.e. length, pavement type, etc.). In this analysis, 12,007 public and private airports, of any runway length, where used for the extraction of flights from the ETMS flight database.

An extensive data quality assurance process was used to filter data with missing information fields such as aircraft type. The retained data accounted for 70% of the total number of flights from the original data. A total of 14.1 million domestic flights and 5.9 million international flights were analyzed (after the filtering process).

The data was also filtered into categories of aircraft (in order to understand the differences in terms of network structure between various modes of operations). These categories included; wide body jets (e.g. Boeing 767, Airbus 300), narrow body jets (e.g. Boeing 737s, Airbus 318/319/320/321), regional jets (e.g. Bombardier CRJ200, Embraer E145), business jets (e.g. Cessna CJ1, Hawker 400), turboprops (e.g. Q400, ATR42) and piston aircraft (e.g. Cessna 172, Pipers).

From this detailed flight data, network adjacency matrices[2] were constructed for each of the aircraft types. Figure 36 shows the graphical representation of the networks that were extracted from the ETMS traffic data and plotted according to the frequency of flights on each route (ranging from 1 to 1000 flights per year).

Figure 36 shows that the layers of the U.S. air transportation network are not homogenous both in terms of frequency (i.e. number of flights taking place per year on each arc) and structure (i.e. spatial patterns formed by arcs). The wide body jet network is primarily composed of sparse long-haul cross-country flights with fairly high frequency.

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[1] Data source: United States Department of Transportation Federal Aviation Administration, Form 5010 data, available at: http://www.gcr1.com/5010web, last accessed: January 2008.

[2] Note: a network adjacency matrix is an n by n matrix, where n is the number of nodes in the network, with binary entries indicating whether there is an edge between two nodes (i.e. 1 denotes the existence of an edge and conversely 0 indicates the absence of edges). For weighted networks, the network weighted adjacency matrix is an n by n matrix, where the entries indicate the weight on the edge (e.g. frequency of non-stop flights between two airports in the case of the air transport network).

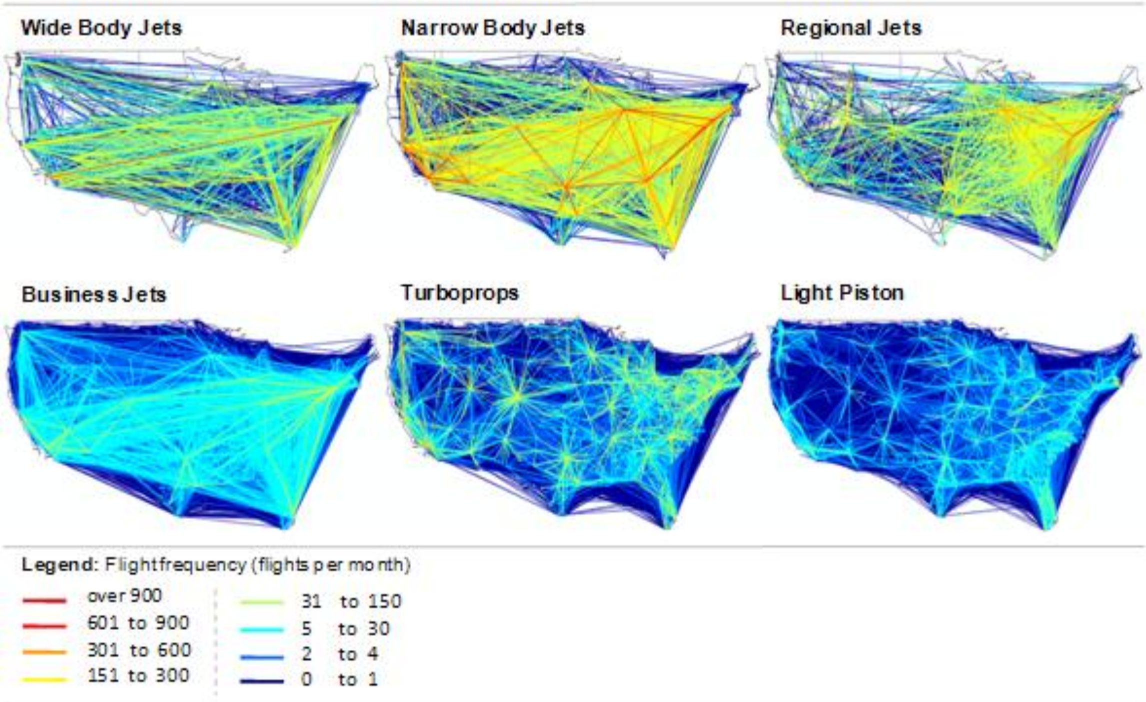

Figure 36: Illustration of the U.S. air transportation networks (by type of aircraft)

The narrow body jet network is denser with relatively shorter range flights with some routes with very high frequency (i.e. over 900 flights per month). The network of flights flown by regional jets is sparse with high frequency routes mainly centered on connecting hubs such as Chicago/O'Hare (ORD), Atlanta (ATL), Denver/Intl (DEN) which is consistent with the use of regional jets as hub feeders.

While the wide body, narrow body and regional jet networks are relatively sparse, the network of flights flown by business jets, turboprops and light piston aircraft are denser. The business jet network is dense with low frequency routes. However, there are a few popular (i.e. medium frequency) routes between key metropolitan regions such as New York, Chicago, Dallas, Atlanta, Miami, Denver, Los Angeles, etc. The turboprop network exhibits both a dense set of low frequency routes and a localized set of routes that are centered on key airports. This latter part of the network is formed by feeder flights in and out of connecting hub airports. Finally, the piston aircraft network which is the network that spans across the largest number of airports is composed mainly of low frequency routes. This is consistent with the general type of use and unscheduled operations performed by light piston aircraft.

5.1.2 Airport level cross-sectional analysis of the U.S. air transportation network

a. Description of the U.S. air transportation (flight) network

While Figure 36 shows the different layers of the U.S. air transportation network decomposed by aircraft type, the overall U.S. air transportation network is a woven set of network layers. These layers were recombined to form the U.S. air transportation network (Figure 37).

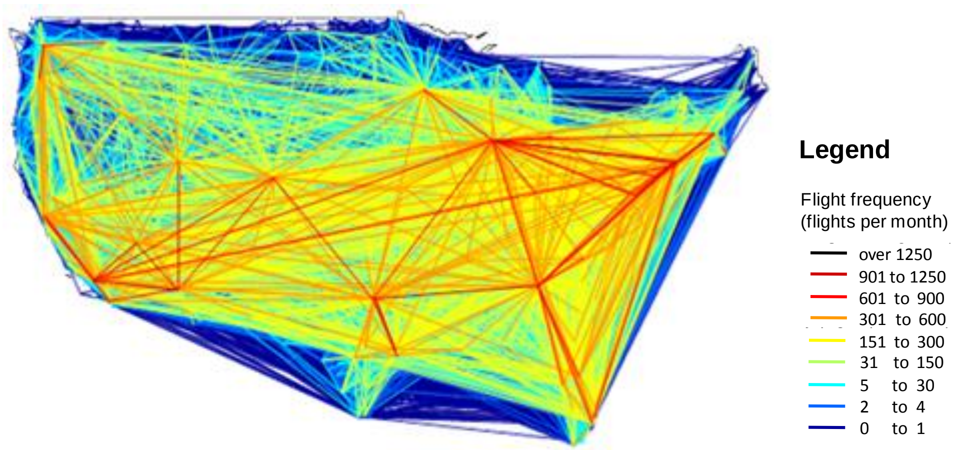

Figure 37: Air transportation network in the United States (domestic routes represented only)

This overall network is composed of a large set of low frequency routes and a more limited set of very high frequency routes. Figure 37 shows that despite the large number of nodes present in this network aircraft traffic is concentrated around few key airports. One way to measure this non-homogeneity of the structure of the network is through the construction and analysis of the degree and flight-weighted degree distributions of the network using network theories (cf. Chapter 3).

b. Analysis of the structure of the U.S. air transportation (flight) network

As presented in Chapter 3, one of the key metrics that characterize the structure of a network is the degree distribution. The degree of a node is the number of incoming and outgoing arcs to and from this node (i.e. number of routes connecting one airport to other airports in the network). The degree distribution of the U.S. air transportation network (with airport nodes) was computed and plotted (Figure 38). As shown in Figure 38, a large number of nodes (i.e. airports) exhibit low number of destinations (i.e. node degree) while there are very few airports that have large number of destinations.

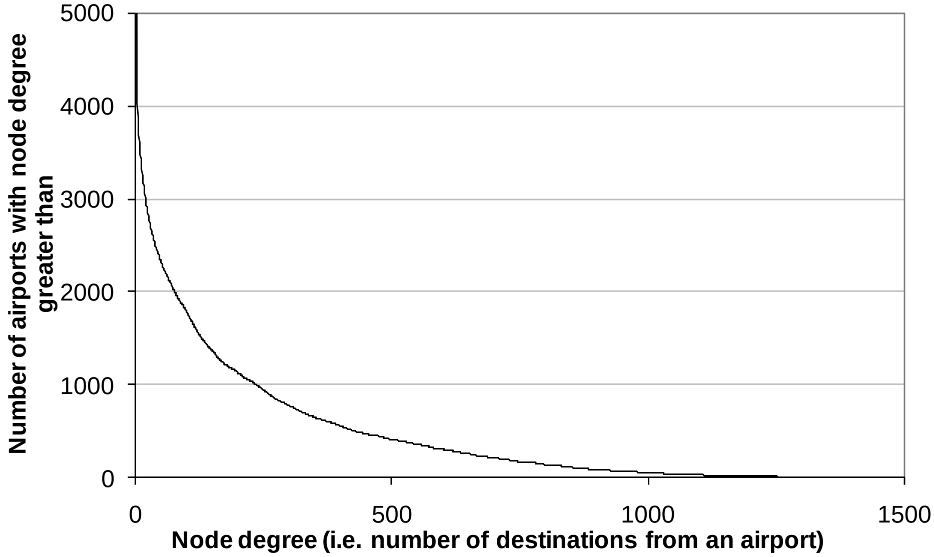

Figure 38: Degree distribution of the U.S. air transportation network (linear-linear plot)

As presented in Chapter 3, because of the limited number of nodes with high degrees it is generally difficult to evaluate the function that describes the upper tail of the distribution. As a result, cumulative distributions shown on log-log plots are used to identify power law distributions. Figure 39 shows the distribution of the number of airports with a degree greater than a certain value versus this degree value.

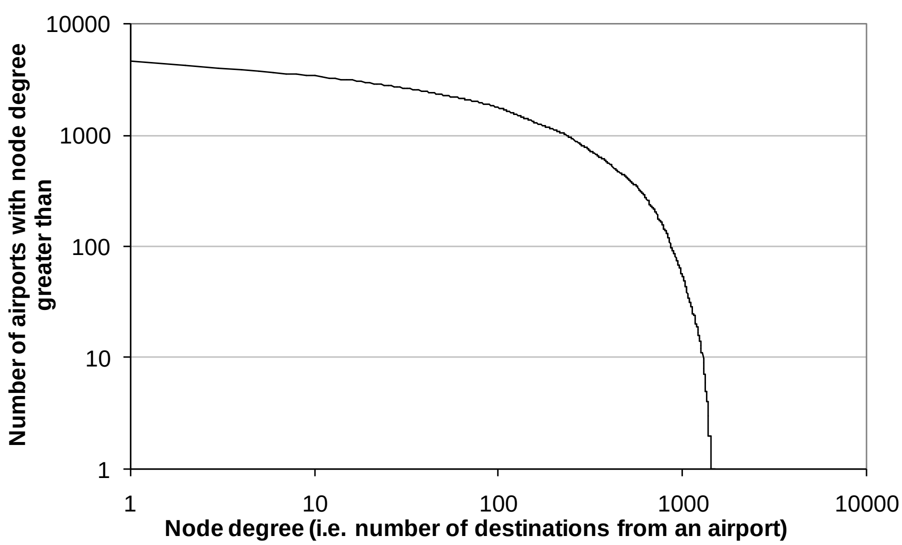

Figure 39: Degree distribution of the U.S. air transportation network (log-log plot)

This degree distribution is not a negative power law distribution. As a result, the network that it represents is not a scale-free network. This observation is consistent with the analysis of the un-weighted network performed by Barrat et al. (2003) who hypothesized that spatial constraints (i.e. the number of destination reachable from airport nodes in the network) constrained the scale of the un-weighted air transportation network.

While the degree of a node captures information relative to the structure of the network (i.e. distribution of arcs across nodes) it does not take into account the flows on the arcs. Figure 40 extends the concept of un-weighted degree to that of weighted degree including information on the different flows taking place on the network. For the purpose of this analysis, the degree of the nodes will be weighted by the number of flights on each arc in the network.

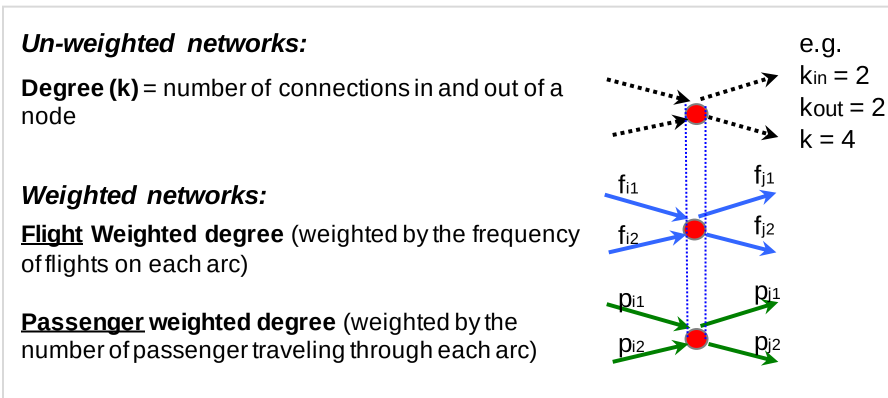

Figure 40: Definition and notional concept of node degrees and node weighted degrees

Figure 41 shows the flight weighted degree distribution of the U.S. air transportation network. It was found that there were large number of nodes that had very low flight weighted degree (i.e. flights per year) and very few nodes that have large number of flights. Similarly to the analysis of the un-weighted network the transformation of the linear-linear plot into a log-log plot was performed to identify a potential power law distribution.

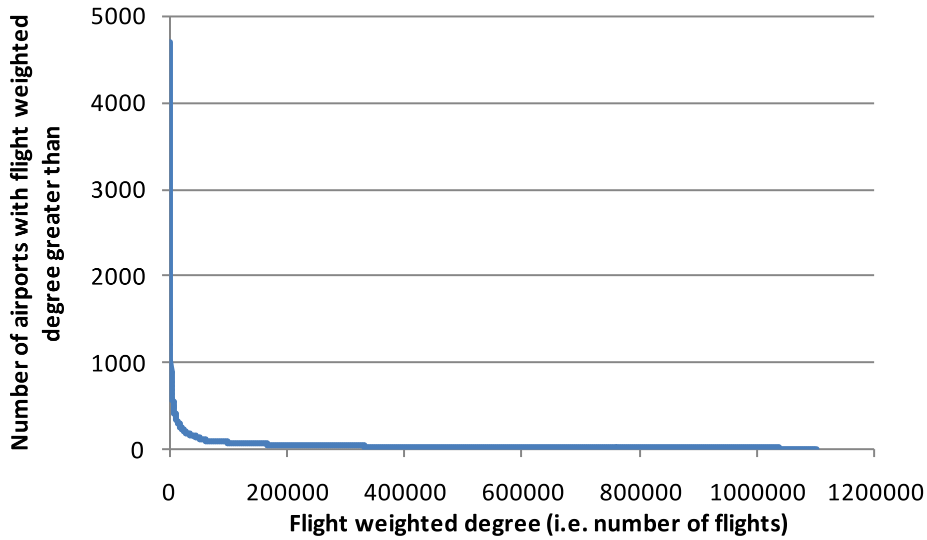

Figure 41: Flight weighted degree distribution of the U.S. air transportation network (linear-linear plot)

Figure 42 shows the transformation of the plot in Figure 41 into a log-log plot. It shows that the flight weighted degree distribution does follow a negative power law distribution for flight weighted degree smaller than approximately 250,000 flights per year. Beyond 250,000 flights per year, the distribution does not fit the negative power law.

Due to the fact that the distribution of weighted degrees has a finite upper limit (i.e. 1,063,000 flights) and the way the power law is constructed, the deviation from the power law fit (i.e. straight line) is greater than it would be for a distribution of non-finite flight weighted range. In order to verify the validity of the observation of a non-power law part in the distribution, a test involving a correction factor was developed. The details of this iterative test and the correction of the tail of the distribution are presented in "Appendix A: Network Analysis". The corrected distribution is displayed in the inset of Figure 42 and shows that this part of the distribution is indeed not a power law.

The identification of a power law distribution across the full range of weighted degree (annual airport operations) would have been indicative of a scale-free network.

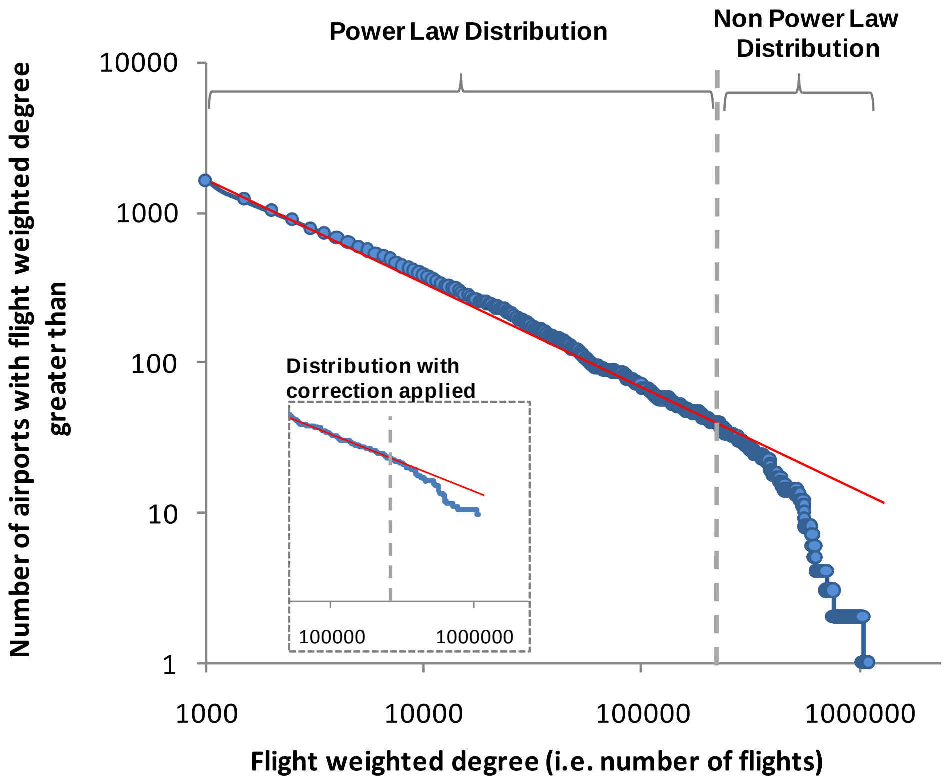

Figure 42: Flight weighted degree distribution of the U.S. air transportation network (log-log plot)

c. *Hypothesis explaining the non-scale-free flight weighted degree distribution*

The identification of a non-power part in the distribution (i.e. ranging from 250,000 and 1,063,000 flights) suggests that there are limits to the scale in this network and that capacitated nodes (i.e. capacity constrained airports) are present in this part of the distribution. The non-power law part of the distribution presented in Figure 42 was composed of 33 airports listed in Table 2.

Table 2: Airports within the non-power law part of the weighted degree distribution of the U.S. air transportation network (ranked by decreasing flight weighted degree)

Airport code	Airport name	Flight weighted degree (i.e. annual number of operations)
ORD	Chicago/O'Hare	1,063,000
ATL	Atlanta	1,035,000
DFW	Dallas/Fort Worth	760,000
LAX	Los Angeles/Intl	707,000
DEN	Denver/Intl	629,000
PHL	Philadelphia	623,000
IAD	Washington/Dulles	611,000
CLT	Charlotte	598,000
IAH	Houston/Intercontinental	564,000
PHX	Phoenix	560,000
MSP	Minn./St. Paul	557,000
DTW	Detroit	555,000
LAS	Las Vegas	530,000
CVG	Cincinnati	515,000
EWR	New York/Newark	455,000
BOS	Boston/Logan	441,000
LGA	New York/LaGuardia	434,000
SLC	Salt Lake City	419,000
MEM	Memphis	400,000
SFO	San Francisco/Intl	392,000
MCO	Orlando/Intl	386,000
MIA	Miami/Intl	386,000
SEA	Seattle	370,000
JFK	New York/Kennedy	358,000
BWI	Washington/Baltimore	330,000
MDW	Chicago/Midway	327,000
FLL	Fort Lauderdale	315,000
DCA	Washington/Reagan	312,000
STL	St Louis/Lambert	299,000
PIT	Pittsburgh	292,000
TPA	Tampa	277,000
CLE	Cleveland	277,000
PDX	Portland International	261,000

It is clear that some of these airports (i.e. nodes) are constrained by capacity. All 4 U.S. airports that were slot restricted in 2005 (i.e. Chicago/O'Hare (ORD), New York/LaGuardia (LGA), New York/Kennedy (JFK) and Washington/Reagan (DCA)) were found in the non-power law part of the distribution. Slot restrictions are clearly indicative of capacity constraints. Table 3 also shows the list of 33 airports ranked by decreasing percentage of arrivals delayed in 2005. High delays are also indicative of airport capacity constraints.

Table 3: Airports ranked by decreasing percentage of operations delayed in 2005[1]

Airport code	Airport name	Percentage of arrivals delayed in 2005	Capacity restrictions
EWR	New York/Newark	32.7	
LGA	New York/LaGuardia	29.0	Slot restricted
JFK	New York/Kennedy	27.2	Slot restricted
ATL	Atlanta	25.7	
PHL	Philadelphia	25.7	
BOS	Boston/Logan	25.2	
FLL	Fort Lauderdale	25.2	
MIA	Miami/Intl	24.7	
SFO	San Francisco/Intl	23.5	
IAD	Washington/Dulles	21.2	
LAS	Las Vegas	21.1	
TPA	Tampa	20.9	
SEA	Seattle	20.8	
MCO	Orlando/Intl	20.7	
MEM	Memphis	20.5	
ORD	Chicago/O'Hare	20.4	Slot restricted
PDX	Portland International	20.3	
CLE	Cleveland	20.0	
BWI	Washington/Baltimore	19.6	
MDW	Chicago/Midway	19.2	
LAX	Los Angeles/Intl	18.8	
CLT	Charlotte	18.7	
PIT	Pittsburgh	18.3	
MSP	Minn./St. Paul	18.1	
DTW	Detroit	17.5	
PHX	Phoenix	17.1	
DCA	Washington/Reagan	16.9	Slot restricted
IAH	Houston/Intercontinental	16.9	
SLC	Salt Lake City	16.5	
CVG	Cincinnati	16.1	
DFW	Dallas/Fort Worth	16.1	
DEN	Denver/Intl	15.8	
STL	St Louis/Lambert	15.8	

Given the existence of regulatory measures to limit activity (i.e. slot restrictions) and the presence of high delays (which indicate capacity shortfall based on queuing theory) at airports in the non-power law part of the distribution, capacity constraints constitute a reasonable hypothesis for the limits to scale observed in Figure 42. Regional market opportunities and dynamics were also hypothesized as having an impact on the relative size (i.e. weights) of these airport nodes.

[1] Data source: US Federal Aviation Administration (FAA), Aviation System Performance Metrics (ASPM), Airline Service Quality Performance (ASQP), available at: http://aspm.faa.gov/aspm/entryASPM.asp, last accessed; April 2008.

5.1.3 Regional level cross-sectional analysis of the U.S. air transportation network

a. Analysis of regional airport systems in the United States

Because of the emergence of secondary airports in the vicinity of primary airports (Bonnefoy, et al., 2005), resulting in the development multi-airport systems, additional insights can be gained by examining the system at the regional level. The 33 airports that were identified in the non-power law part of the distribution formed the basis for a study of regional airport systems. Those were defined, for the purpose of this analysis, as all airports within 60 miles of the 33 airports in the non power law part of the distribution. Figure 43 shows the geographical distribution of these regional airport systems.

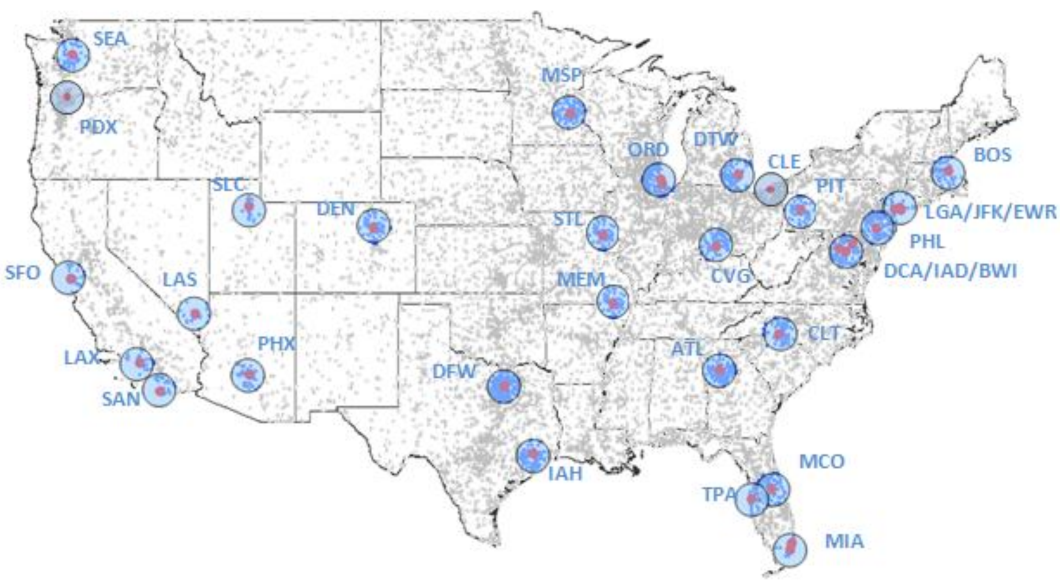

Figure 43: Regional airport systems in the United States around the 33 airports part of the non power law distribution

To assess the role of airports in the provision of commercial traffic (i.e. passenger traffic), this analysis considered all the airports with more than 500,000 passengers in 2005. A set of two or more significant airports that serve commercial passenger traffic (i.e. more than 500,000 passengers in 2005) in a metropolitan region defined a multi-airport system. The set of airports within multi-airport systems were categorized into primary and secondary airports. A primary airport was defined as serving more than 20%

of the total passenger traffic served in the multi-airport system. A secondary airport was defined as an airport serving between 1% and 20% of the total passenger traffic in the multi-airport system (and serving more than 500,000 passengers per year). Figure 44 illustrates the multi-airport systems serving the metropolitan regions of Boston and New York.

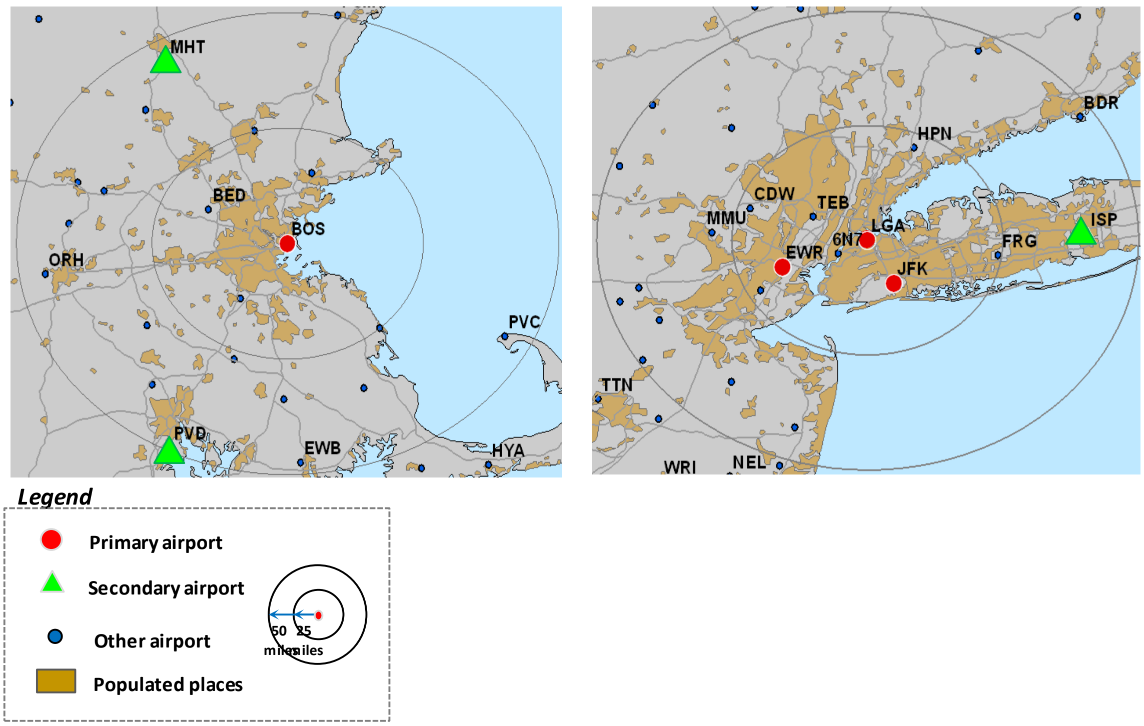

Figure 44: Illustration of two multi-airport systems in the United States (Boston and New York)

As illustrated in Figure 44, the Boston region is centered on Boston/Logan (BOS). It features two other significant airports; Boston/Manchester (MHT) in New Hampshire and Boston/Providence (PVD) in Rhode Island. Boston/Logan is considered a primary airport while Boston/Manchester and Boston/Providence are considered secondary airports.

While Boston is an example of a multi-airport system with one single primary airport, more complex multi-airport systems such as the New York multi-airport system exit. This system has three primary airports; New York/LaGuardia (LGA), New York/Kennedy (JFK) and New York/Newark (EWR). In addition, the region also has one secondary airport located on Long Island; New York/Islip (ISP) (Figure 44).

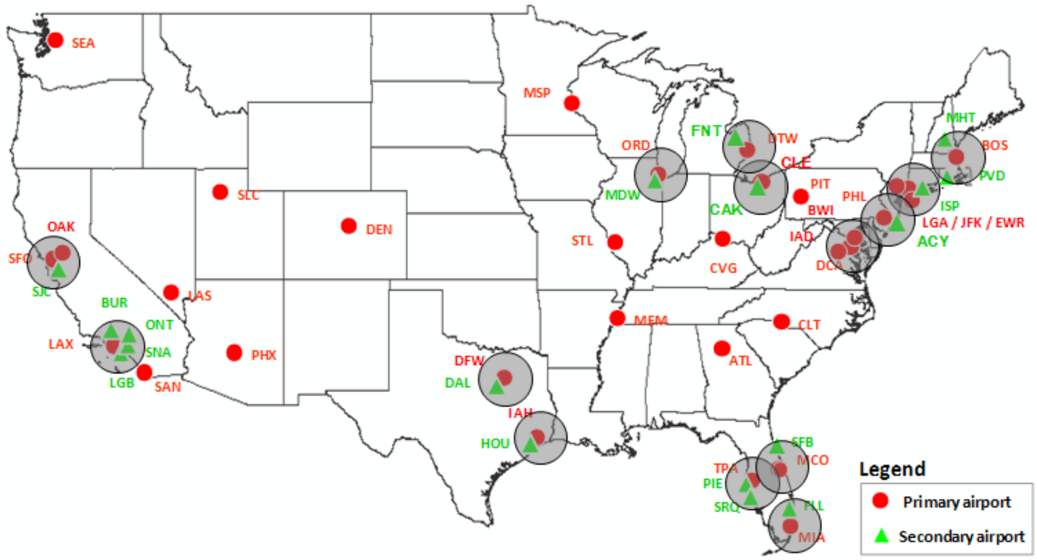

Figure 45: Primary and secondary airports in the United States (within the regional airport systems around the top 33 airports)

Figure 45 and Table 4 show a total of 20 primary and 17 secondary airports within 14 multi-airport systems identified in the United States.

Table 4: Primary and secondary airports within 14 multi-airport systems in the United States

Multi-Airport System	Airport code	Airport name	Airport type
Boston	BOS	Boston/Logan	Primary
Boston	MHT	Boston/Manchester	Secondary
Boston	PVD	Boston/Providence	Secondary
Chicago	ORD	Chicago/O'Hare	Primary
Chicago	MDW	Chicago/Midway	Secondary
Cleveland	CLE	Cleveland/Hopkins	Primary
Cleveland	CAK	Cleveland/Akron-Canton	Secondary
Dallas	DFW	Dallas/Fort Worth	Primary
Dallas	DAL	Dallas/Love Field	Secondary
Detroit	DTW	Detroit/Metropolitan	Primary
Detroit	FNT	Detroit/Bishop	Secondary
Houston	IAH	Houston/Intercontinental	Primary
Houston	HOU	Houston/Hobby	Secondary
Los Angeles	LAX	Los Angeles/Intl	Primary
Los Angeles	BUR	Los Angeles/Burbank	Secondary
Los Angeles	LGB	Los Angeles/Long Beach	Secondary
Los Angeles	ONT	Los Angeles/Ontario	Secondary
Los Angeles	SNA	Los Angeles/Santa Ana	Secondary
Miami	FLL	Miami/Fort Lauderdale	Primary
Miami	MIA	Miami/Intl	Primary
New York	JFK	New York/Kennedy	Primary
New York	LGA	New York/LaGuardia	Primary
New York	EWR	New York/Newark	Primary
New York	ISP	New York/Islip	Secondary
Orlando	MCO	Orlando/Intl	Primary
Orlando	SFB	Orlando/Sanford	Secondary
Philadelphia	PHL	Philadelphia/Intl	Primary
Philadelphia	ACY	Philadelphia/Atlantic City	Secondary
San Francisco	OAK	San Francisco/Oakland	Primary
San Francisco	SFO	San Francisco/Intl	Primary
San Francisco	SJC	San Francisco/San Jose	Secondary
Tampa	TPA	Tampa/Intl	Primary
Tampa	SRQ	Tampa/Sarasota	Secondary
Tampa	PIE	Tampa/St Petersburg	Secondary
Washington	BWI	Washington/Baltimore	Primary
Washington	IAD	Washington/Dulles	Primary
Washington	DCA	Washington/Reagan	Primary

The remaining 13 airports from the set of 33 airports are single primary airport systems as shown on Figure 45. These airport systems may develop into multi-airport systems in the future as the traffic on the network expands and these primary airports become constrained by capacity.

b. *Analysis of the U.S. air transportation network with multi-airport systems aggregated into single-nodes*

Because the primary and secondary airports identified in each of the multi-airport system serve the demand for air transportation within the same metropolitan region, these airports can be aggregated into a multi-airport system node. Figure 46 shows the graphical representation of the U.S. air transportation network with multi-airport systems aggregated into single nodes. Similarly to the single airport node network (Figure 37), the flight weighted degree distribution of this new network was examined.

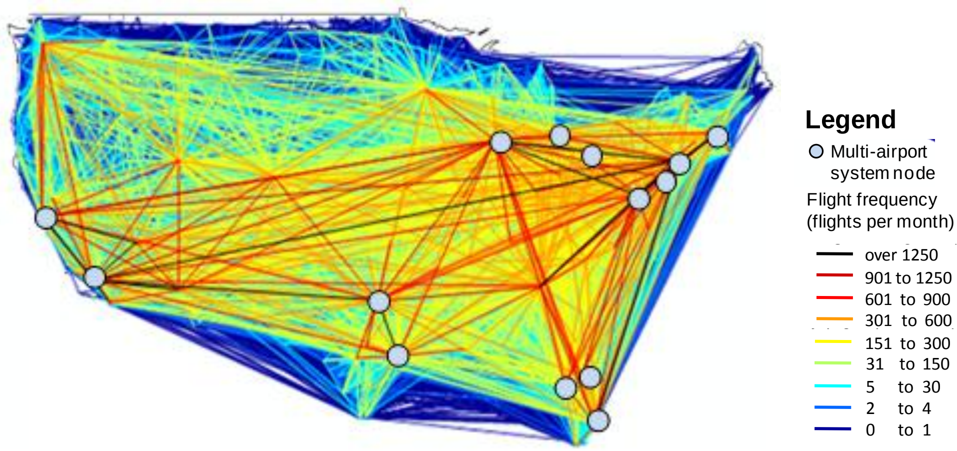

Figure 46: Air transportation network in the United States with multi-airport systems aggregated into single nodes

As shown in Figure 47, with the analysis of the U.S. air transportation network at the regional level, the air transportation network was found to follow a power law distribution across the entire range of flight weighted degrees. This finding suggests that the evolution of the network through the development of multi-airport system nodes was key to the ability of the system to scale at capacity constrained nodes.

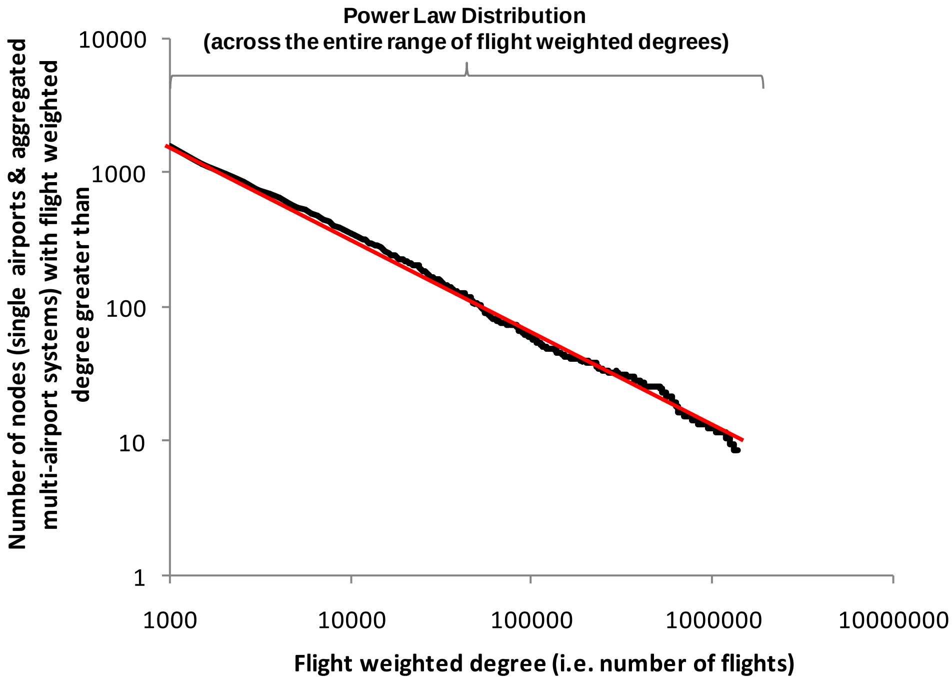

Figure 47: Flight weighted degree distribution of the U.S. air transportation network with aggregated multi-airport nodes (with correction applied[1])

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[1] Note: Appendix 1 presents in detail the process of correcting cumulative degree and flight weighted degree distributions with finite degrees and weighted degrees.

5.2 Time Series Analysis of the U.S. Air Transportation Network

5.2.1 Data sources and methodology

The cross-sectional analysis of the air transportation network revealed that the network was scale-free at the regional level (i.e. the flight weighted degree distribution followed a negative power law). While this analysis provided insights into the structure of the network, the objective of this research to investigate how the air transportation system scaled over time motivated a more in-depth analysis of the evolution of the network. A time series analysis of the network was performed.

From network theory[1], the presence of a negative power law distribution implies that the growth of the network can be based on preferential attachment (Newman, 2003), (Krapivsky, et al., 2001) and (Li, et al., 2005). This preferential attachment dynamic implies that a node grows proportionally to its size in the network[2]. Equation 5 shows the linear relationship between the relative growth rate and the relative average size of a node in the network.

Equation 5:

$$\frac{\frac{\partial w_i}{\partial t}}{\sum_{i\in N}\frac{\partial w_i}{\partial t}} \propto \frac{w_i}{\sum_{i\in N} w_i} \quad \forall i \in N$$

From an air transportation system perspective, the preferential attachment mechanism implies that new flights are added to airports proportionally to their size in the network. As a corollary, airports that already have many flights are more likely to attract additional flights than those with little or no traffic. This growth dynamic is consistent with network planning behaviors generally observed in the air transportation industry. Airlines tend to add flights at airports they already serve rather than at non-utilized airport that are closely located to these major airports. This dynamic of preferential addition (i.e. preferential attachment) of flights at the major airport serving a region, also referred to as concentration of traffic, is described by de Neufville et al. (2003).

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[1] Note: cf. Chapter 3: Related Work, Section 3.3; Scale-free and Scalable Networks: Theory and Models.
[2] Note: This assumption is valid for unconstrained networks.

In order to analyze the evolution of nodes in the network, an analysis of the historical growth rate of airport traffic was performed. This analysis was based on historical data from the FAA Terminal Area Forecast database[1] that covered a time period ranging from 1976 to 2005. For the purpose of this analysis, data on operations by air taxi and air carriers was used[2]. To evaluate whether nodes in the network were following the preferential attachment dynamic (i.e. evolving according to Equation 5), the relative annual growth of each node and the relative average size of nodes were computed. The annual growth of nodes was computed as the slope of the linear regression on traffic between 1976 and 2005. The average size of a node was computed as the arithmetic mean of the traffic between 1976 and 2005.

Similarly to the cross sectional analysis, this times series analysis was performed at the airport level and also at the regional level. The following section presents the results of both analyses.

Regression and statistical analyses were also performed to test the hypothesis of preferential attachment and to assess the impacts of node aggregation. These analyses were based on bootstrap method to correct for heteroscedasticity in the datasets (cf. section 5.2.4).

5.2.2 Airport level time series analysis of the U.S. air transportation network

As shown on Figure 48, the relative annual growth versus relative average size of the nodes in the network generally follows a linear fit. However, significant deviations from the linear relationship were found for individual airports. The alignment of nodes along the linear relationship would have been indicative of preferential attachment growth.

[1] Data source: Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: February 2007.

[2] Note: While Figure 48 and Figure 49 shows the results of the analysis of using data on operations by air taxi and air carrier, a more complete analysis of the evolution of traffic at airports was performed. This extended analysis was based on data for passenger enplanements and total operations. Appendix A-2 shows the results of these four additional analyses (i.e. evolution of nodes for individual airports and aggregated multi-airports systems into single nodes).

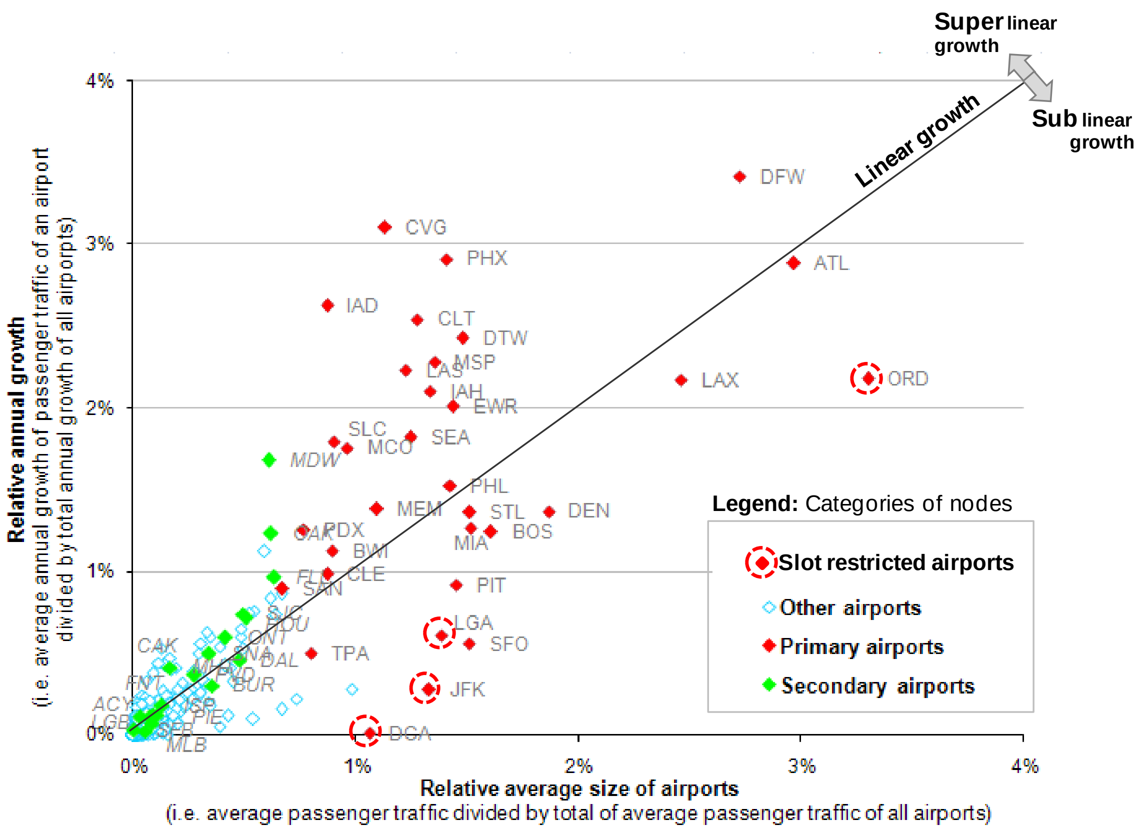

Figure 48: Relative annual growth versus relative size of airports in the United States from 1976 to 2005

The observed deviation from the linear growth model reflects capacity constraints that limit the growth of certain airports (e.g. Washington/Reagan (DCA), New York/Kennedy (JFK), New York/LaGuardia (LGA), and Chicago/O'Hare (ORD). In fact, 4 out of the 33 airports are constrained by capacity through the use of slot restrictions in 2005 exhibit strong sub-linear growth[1]. Other airports in the sub-linear regime; New York/Newark (EWR), Atlanta (ATL), Boston/Logan (BOS), and San Francisco/Intl (SFO) exhibit significant delays that are signs of airport congestion. Airports above the linear growth line (i.e. exhibiting super-linear growth); Cincinnati (CVG), Washington/Dulles (IAD), and Dallas/Fort Worth (DFW) are airports that grew significantly because they became connecting hubs during the time horizon analyzed.

[1] Note: In 2008, there were only three airports (Washington/Reagan (DCA), New York/LaGuardia (LGA), and Chicago/O'Hare (ORD)) in the United States that were slot restricted. In 2005 and the time of the analysis, New York/Kennedy (JFK) was also a slot restricted airport. The lift of slot restrictions and the increase in traffic resulted in the significant increase of delays that have been observed throughout the year 2007. The historical evolution of delays at New York/Kennedy is presented in Chapter 2.

5.2.3 Regional level time series analysis of the U.S. air transportation network

The time series analysis of the historical evolution of nodes in the network was also conducted at the regional airport system level (Figure 49). Similarly to the cross-sectional analysis, the aggregation of nodes (i.e. airports within a multi-airport system) was performed. The aggregation of primary and secondary airports that serve the same metropolitan region resulted in the construction of 14 multi-airport system nodes. Figure 49 shows the relative annual growth versus relative size for single airport nodes and multi-airport system nodes.

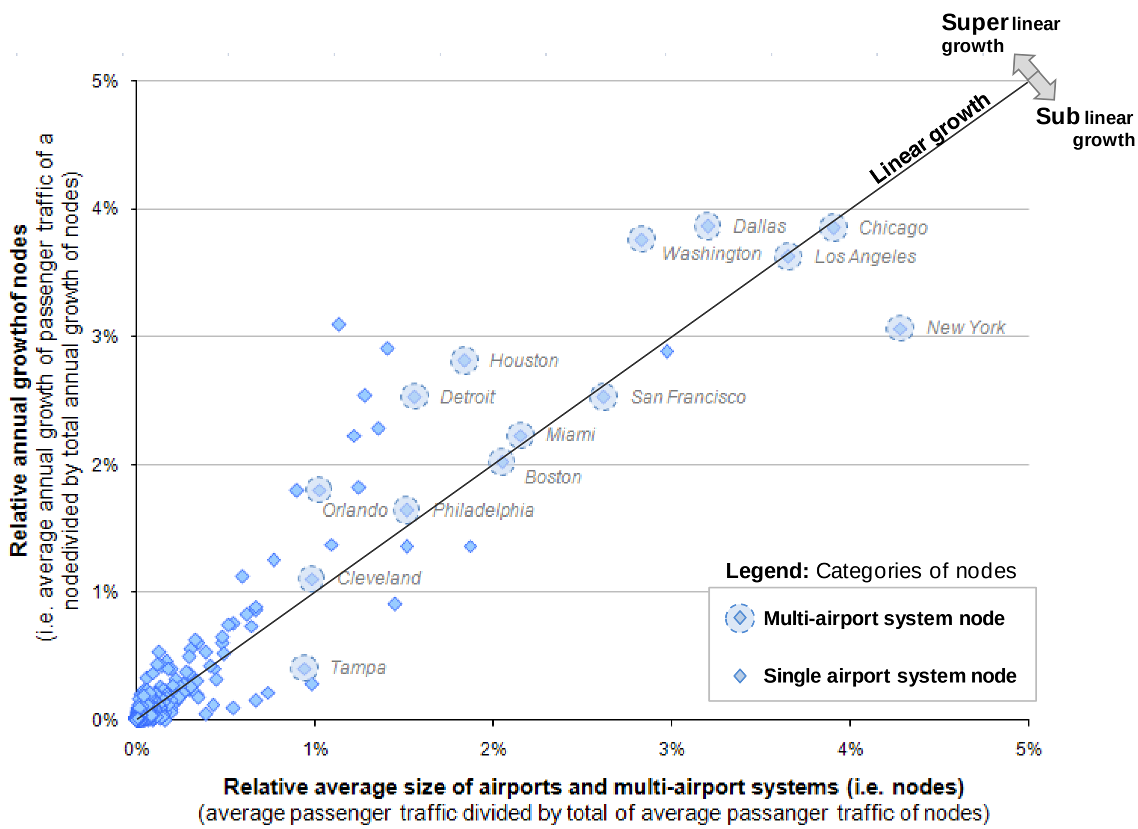

Figure 49: Relative annual growth versus relative size of airports and multi-airport systems in the United States from 1976 to 2005

The process of aggregation reduced the deviation from the linear relationship (cf. statistical analysis section 5.2.4). In fact, 7 out of the 14 multi-airport system nodes exhibit linear growth more closely[1].

[1] Note: The deviation from the linear growth model slightly increased, following the aggregation process, in the case of the Houston and Dallas multi-airport systems. This is due to the particular history and

Discussion on multi-airport system nodes that exhibit sub-linear growth

The deviation from the linear relationship that was observed for the New York multi-airport system is due to airport and multi-airport system constraints (Figure 50).

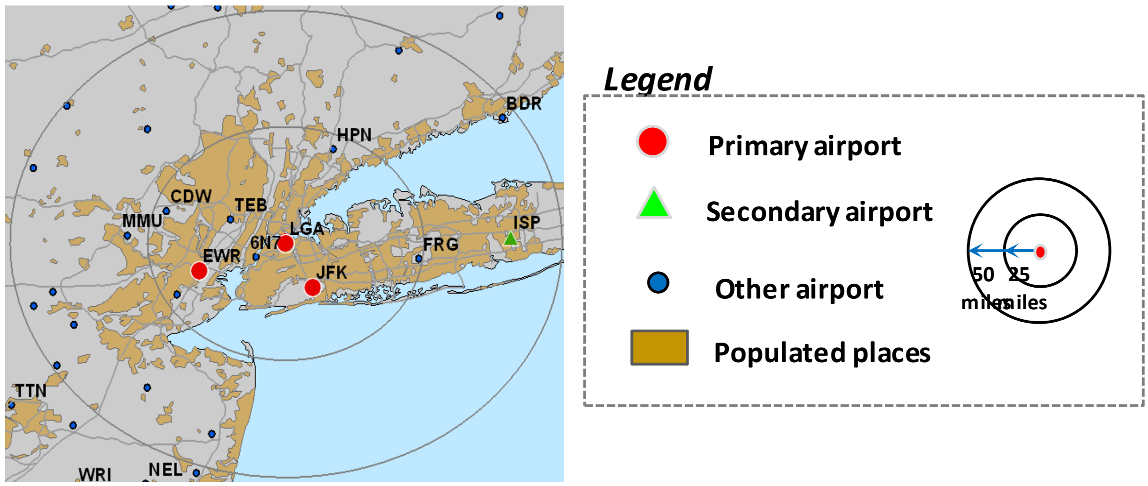

Figure 50: Map of the New York multi-airport system

As shown on Figure 51, the three major airports in the New York region exhibit high levels of delays that are indicative of capacity constraints. In addition, New York/LaGuardia is slot restricted which artificially limits the level of delays at this airport. It is also a strong constraint on the potential growth of this airport. As of 2008, caps on the number of hourly operations have also been set for New York/Newark and New York/Kennedy in order to limit flight delays and congestion.

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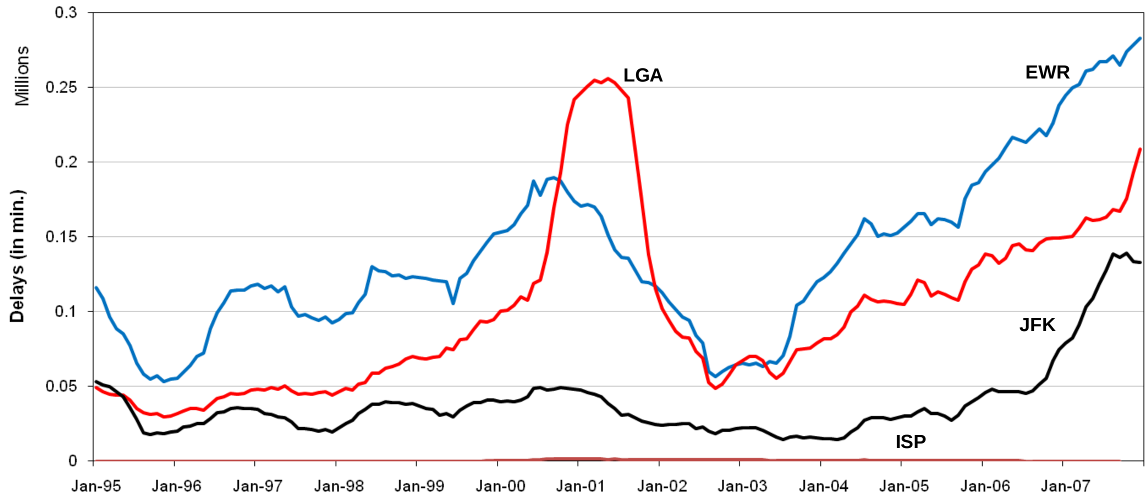
configuration of these airport systems that allowed both airports to growth according to super linear growth. In both cases, the current secondary airports (i.e. Dallas/Love Field and Houston/Hobby) were the original airports in the region. However, the traffic of both airports was displaced to newly build high capacity airports (i.e. Dallas/Fort Worth and Houston/Intercontinental) in 1974 and 1969 respectively, resulting in inexistent to very little traffic at the original airports. However, the original airports were not closed. In these two cases, both the original airports and the newly build airport were able to grow. While the new airports served domestic and international traffic by legacy carriers, the original airports reemerged with the development of low-cost carriers (i.e. Southwest Airlines).



Data source: US Federal Aviation Administration (FAA) OPSNET data.
Note: Due to the way delays are defined and are reported, OPSNET data underestimates the true extent of delays. The use of this data in this figure is for trend analysis purposes (cf. footnote for additional details on OPSNET data).

Figure 51: Historical evolution of flight delays at New York's airports (New York/LaGuardia LGA, New York/Newark EWR, New York/Kennedy JFK, New York/Islip ISP)

Regional level constraints such as coupling and airspace interactions between the airports in this multi-airport system limit the overall capacity of the system[1]. The implications of these interactions between airports and the limited ability to build airport capacity in multi-airport systems indicate that there is the need to reduce these interactions by developing air traffic management paradigms and tools that would alleviate these interactions. Super Density Operations (SDO) concepts address the effects of these interactions. These concepts are largely based on simultaneous sequencing, spacing, merging, and de-confliction for operations within the terminal airspace (cf. Section: 9.5: Implications for Air Traffic Control).

[1] Note: For details on airport operation interactions with the multi-airport system refer to Section: 9.5: Implications for Air Traffic Control.

5.2.4 Regression and statistical analyses

In order to test the hypothesis of preferential attachment and assess the impacts of airport node aggregation, regression and statistical analyses were performed on the datasets computed in the airport level and regional level time series analyses.

a. Identification of heteroscedasticity

Using ordinary least squares (OLS) as a regression method requires verifying the assumption that the error term has a constant variance across the range of values of the independent variable. Figure 52 shows the distribution of standard error of the relative annual growth of traffic.

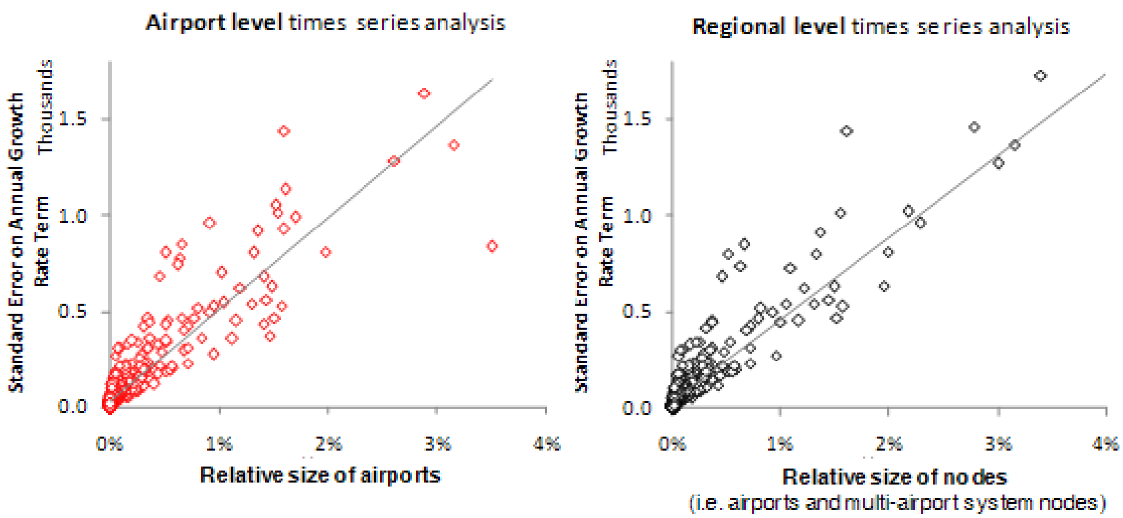


Figure 52: Standard error on the annual growth rate term as a function of traffic share (for datasets from the airport level and regional level analyses)

It is clear from Figure 52 that this standard error is not constant across the range of relative average size of airports and multi-airport systems. In statistics, non-constant standard error across the range of dependent variable is referred to as heteroscedasticity.

a. Bootstrap analysis

The presence of heteroscedasticity in the datasets violates the assumption required for the use of ordinary least squares (OLS). As a result, other regression techniques are required.

While heteroscedasticity tends to underestimate the variance of the coefficients of the regression and inflate t-scores, it does not cause ordinary least squares (OLS) coefficient estimates to be biased. As a result, a bootstrapping method can be used to evaluate the parameters of the regression and construct distribution of those parameters to estimate their unbiased variances and t-scores (Efron, 1979) (Fox, 2002).

Bootstrapping is a modern and computer-intensive approach to statistical inference that is based on re-sampling methods. In this approach, the original dataset is re-sampled into a large number of “bootstrap samples” (of equal size to the original dataset) each of which is obtained by random sampling with replacement from the original dataset. For each of the bootstrap sample, an OLS regression is then performed.

Figure 51 shows the result of the bootstrap analysis from the datasets computed for the analysis of the airport level and regional time series analyses. For this analysis, 10,000 bootstrap samples were generated. OLS regressions were computed for each of them.

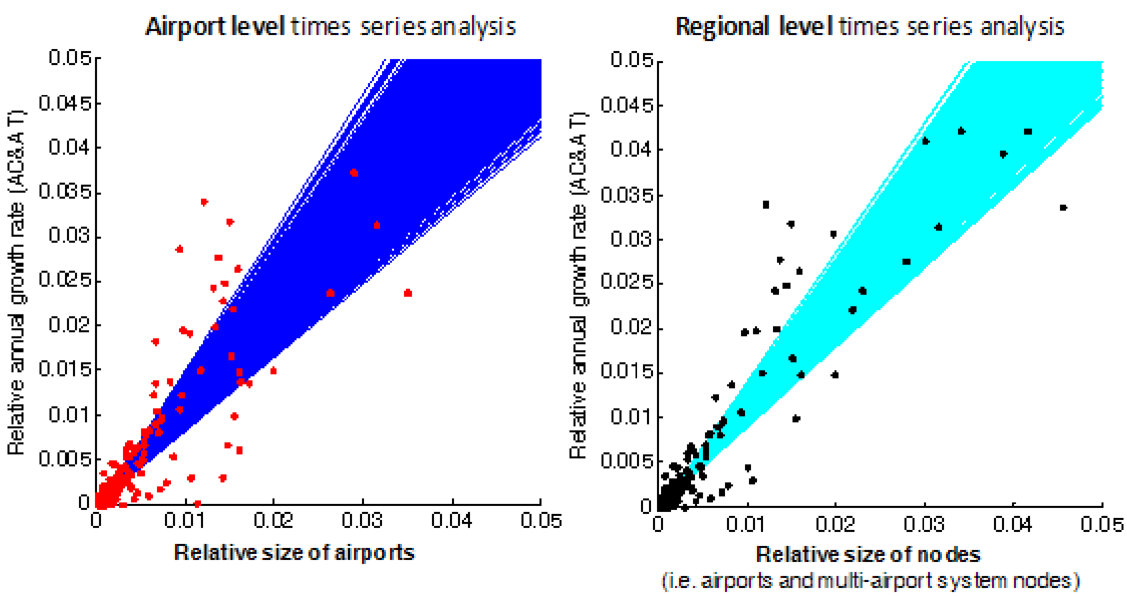


Figure 53: Regression results on 10,000 bootstrap samples from the datasets of the airport level and regional time series analyses

As shown on Figure 51, the generation of samples forms the basis for an array of OLS regressions from which the slope (i.e. beta), intercept and R^2 parameter values can be extracted. These sets of parameters (i.e. sets of 10,000 values, one for each OLS regression) are then used to generate distributions from which mean, variance and t-scores can be computed.

- *Evaluation of regression parameters*

Using the 10,000 bootstrap samples and the results of the OLS regressions, the distributions of the slope of the regression were computed. Figure 54 shows the distributions of the slope (i.e. beta) parameters using 10,000 bootstrap samples from the datasets of the airport level and regional time series analyses.

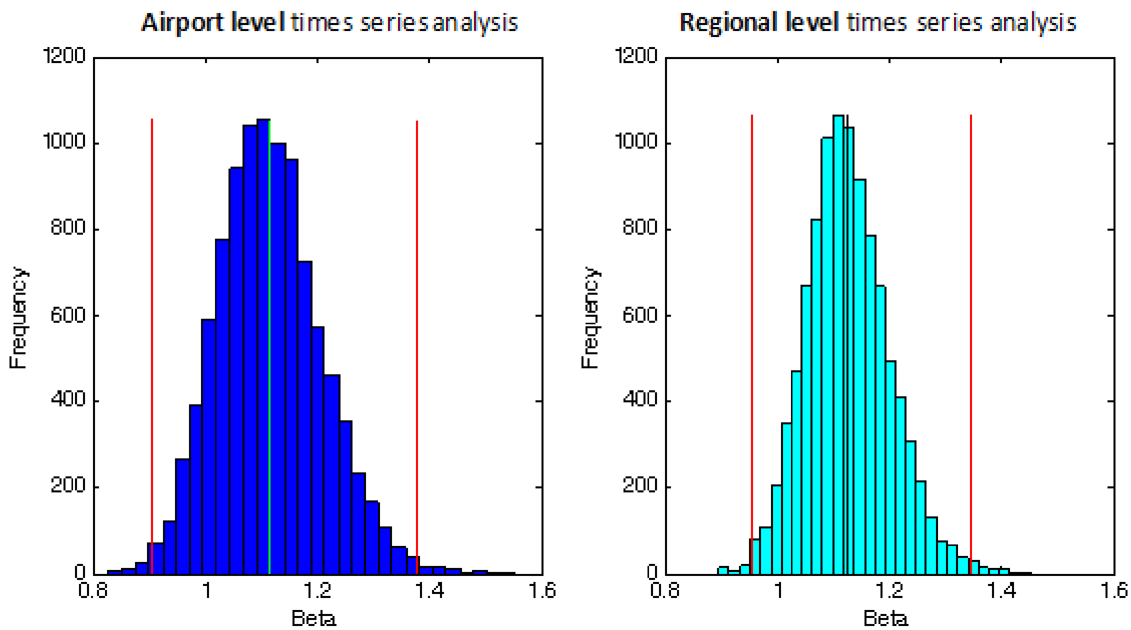


Figure 54: Distributions of the slope (i.e. beta) parameters based on 10,000 bootstrap samples (airport level and regional time series analyses)

The means of the beta parameter were found to be 1.1 for both the airport level analysis and the regional level time series analyses.

Similarly, the distributions of the intercept of the regression were computed. Figure 55 shows the distributions of the intercept parameters using 10,000 bootstrap samples from the datasets of the airport level and regional time series analyses.

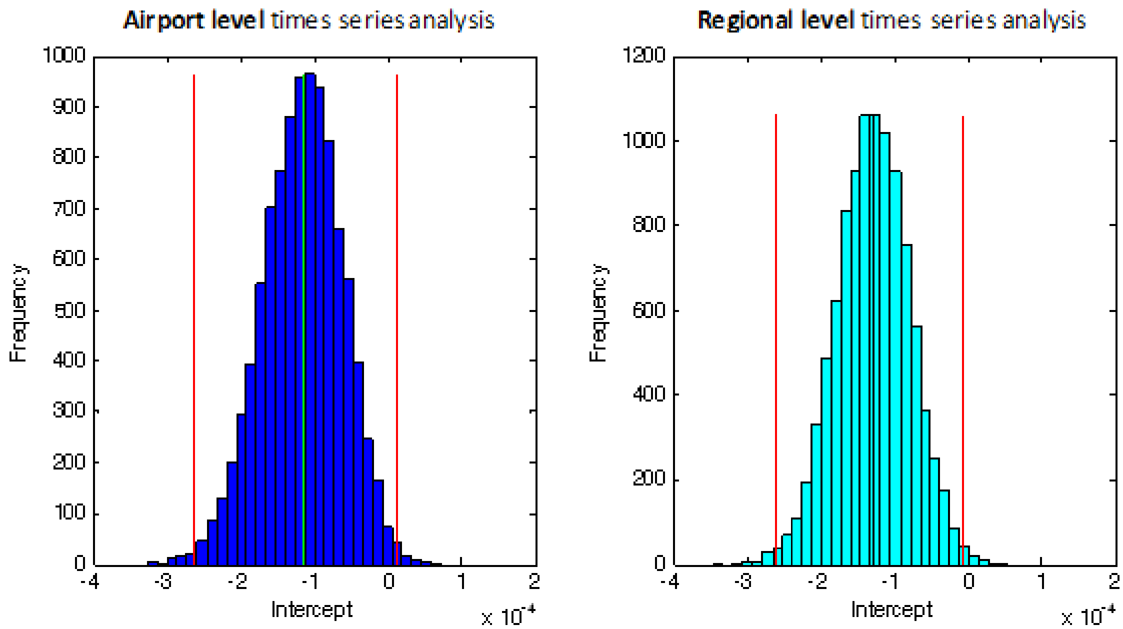


Figure 55: Distributions of the intercept parameters based on 10,000 bootstrap samples (airport level and regional time series analyses)

The mean intercept were found to be $-1.2*10^{-4}$ and $-1.3*10^{-4}$ for the airport level analysis and regional level time series analyses respectively.

As a result, Equation 6 and Equation 7 summarize the results of the regressions on the airport level and the regional level time series analyses;

Airport level analysis:

Equation 6:

$$\frac{\dfrac{\partial \hat{traffic}_{ac\&at\,i}}{\partial t}}{\sum_{i\in N}\dfrac{\partial \hat{traffic}_{ac\&at\,i}}{\partial t}} = 1.1*\frac{traffic_{ac\&at\,i}}{\sum_{i\in N} traffic_{ac\&at\,i}} - 1.2*10^{-4}$$

Regional level analysis:

Equation 7:

$$\frac{\dfrac{\partial \hat{traffic}_{ac\&at\,i}}{\partial t}}{\sum_{i\in N}\dfrac{\partial \hat{traffic}_{ac\&at\,i}}{\partial t}} = 1.1*\frac{traffic_{ac\&at\,i}}{\sum_{i\in N} traffic_{ac\&at\,i}} - 1.3*10^{-4}$$

- *Hypothesis testing on R^2*

In order to test the hypothesis that the aggregation process (i.e. transition of single airport systems to multi-airport systems) reduced the deviation from the linear model, a similar process of generating distributions of regression parameters was performed. The distribution of the R^2 values was computed to assess the explanatory power of the regressions and test the hypothesis.

Figure 56 shows the distributions of R^2 values using 10,000 bootstrap samples from the datasets of the airport level and regional time series analyses.

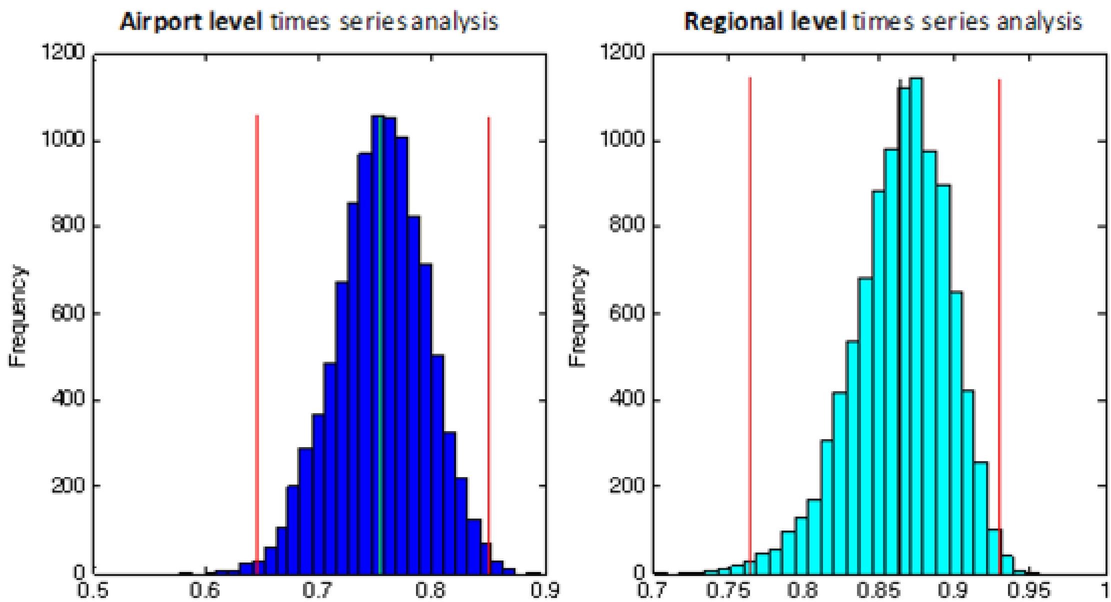


Figure 56: Distributions of the R^2 parameters based on 10,000 bootstrap samples (airport level and regional time series analyses)

The mean R^2 values were found to be 0.75 and 0.86 for the airport level analysis and regional level time series analyses respectively.

The statistical significance of the observed reduction in the deviation from the linear relationship between the relative annual growth and relative size (i.e. increase in R^2 values) was evaluated. Based on the R^2 distributions (Figure 56), the probability that $R^2_{airport}$ was lower than $R^2_{regional}$, was computed (Equation 8).

Equation 8: $$p(\mathrm{R}^2_{\mathrm{airport}} < \mathrm{R}^2_{\mathrm{regional}}) = 1 - \sum_{\mathrm{R}^2_{\mathrm{airport}}=0}^{1} p(\mathrm{R}^2_{\mathrm{airport}}) * \sum_{\mathrm{R}^2_{\mathrm{regional}}=\mathrm{R}^2_{\mathrm{airport}}}^{1} p(\mathrm{R}^2_{\mathrm{regional}}) = 98.4\%$$

As a result, the regression from the regional level analysis provides a better fit than the regression from the airport level analysis (with 98.4% confidence). This increase in

$R^2_{regional}$ (i.e. compared to $R^2_{airport}$) resulting from the aggregation of single-airport nodes into multi-airport system nodes implies that multi-airport system nodes behave overall more closely to preferential attachment than individual airports.

5.3 Summary and conclusions

The cross sectional analysis of the U.S. air transportation (flight) network showed that the network for which airports part of multi-airport systems were aggregated into multi-airport system nodes was scale-free.

By applying the same methodology, the time series analysis of the U.S. flight network showed that multi-airport system nodes historically evolved according to preferential attachment dynamics which is a fundamental dynamic resulting in scale-free networks.

These findings suggest that the transition from single-airport systems to multi-airport systems is key mechanism by which the air transportation system scales.

CHAPTER 6

MULTI-AIRPORT SYSTEMS WORLDWIDE

The network analyses showed that the transition from single-airport to multi-airport systems is and will remain a key mechanism by which the air transportation system scales and will meet growing demand in the future. This chapter presents multi-airport systems worldwide that compose the basis for the detailed multiple-case study analysis.

6.1 Data and Methodology for Identifying Multi-Airport Systems

6.1.1 Definitions

For the purpose of this research, a *multi-airport system* was defined as a set of two or more significant[1] airports that serve commercial passenger traffic in a metropolitan region[2].

These sets of significant airports (serving at least 500,000 passengers per year) are composed of airports with different sizes that can be categorized as primary airports and secondary airports. For the purpose of this research, traffic share (Equation 9) was used to categorize airports.

Equation 9: $$T.S._{airport\ i} = \frac{Passenger\ Traffic_{airport\ i}}{\sum_{all\ airports\ in\ MAS} Passenger\ Traffic}$$

A *primary airport* was defined as an airport serving more than 20% of the total passenger traffic served in the multi-airport system.

[1] Note: Airports that are part of a multi-airport system serve at least 500,000 passengers per year and more than 1% of the total passenger traffic served in the multi-airport system.
[2] Note: For the purpose of this research, a multi-airport system is defined without restriction of airport ownership and country of location of the airports (cf. Definitions in section 3.4.1 in Chapter 3; Related Work). In addition, given the interest and focus of this research, the definition of multi-airport system was limited to the set of commercial airports serving a metropolitan region, disregarding archipelago type multi-airport systems as defined by Garriga (Garriga, 2003).

A *secondary airport* was defined as an airport serving between 1% and 20% of the total passenger traffic served in the multi-airport system (and more than 500,000 passengers per year).

6.1.2 Data and methodology

In order to identify multi-airport systems, data from ICAO[1] and FAA[2] was used. To avoid including airports without significant role in commercial passenger activities, only airports that had more than 500,000 passengers in 2005 were used for further analyses. This filtering process resulted in a set of 451 airports worldwide.

A geographical cluster analysis was performed to identify airports located in the vicinity of each other. In order to compute the distance between airports, a worldwide airport database (DAFIF, 2005) was used. This database provided the latitude and the longitude to all 451 airports. The great circle distance between each airport was computed. In order to at least identify all airports within 60 miles of the center of the city the identification of geographical clusters was based on a 120 mile threshold criterion (i.e. this ensured that in extreme cases where one airport is located 60 miles from the center of a city, another airport that is also located 60 miles in the opposite direction would be identified). Two or more significant airports within 120 miles of each other formed a geographical cluster.

A total of 106 geographical clusters were identified from this analysis. In order to identify multi-airport systems, a detailed analysis of the characteristics of these clusters was performed. The objective of this filtering process was to identify airports that were meeting the definition presented in section 6.1.1. The distance between the airports and the center of the metropolitan region was computed. Because the simple geographical cluster analysis based on distance between airports does not take into account the nature of the terrain across the cluster (i.e. presence of islands or water areas that result in archipelago type airport systems), an analysis of the nature and the configuration of the

[1] Data source: International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008.
[2] Data source: Federal Aviation Administration (FAA), "Terminal Area Forecasts, (historical records)", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: 2007.

terrain across these clusters was performed. In addition, clusters for which the primary (i.e. largest) airport had less than two million passengers in 2005 were not considered.

This filtering process resulted in the identification of 46 multi-airport systems that were considered for further analysis. A total of 12 geographical clusters were identified as archipelago type airport systems (e.g. Lanzarote/Fuerteventura, Jersey/Guernsey, Kona International/Hilo International, Helsinki-Vantaa/Ulemiste), 47 geographical clusters were rejected from further analysis because of excessive distance between airports and the center of the metropolitan region. Finally, 1 geographical cluster was not considered for detailed analysis since the largest airport had less than 2 million passengers.

In the process of the detailed case study analysis (i.e. mostly through the process of airline network analysis), and the literature review process, additional multi-airports were identified. These systems could not be identified in the cluster analysis due to lack of passenger traffic reported through the ICAO database. A total of 13 additional multi-airport systems were added in this phase of the identification process[1].

6.2 Multi-Airport Systems Worldwide: Basis for the Multiple-Case Study Analysis

The multi-airport system identification process resulted in a set of 59 multi-airport systems. Table 5 shows the list of primary airports for which other airports (i.e. other primary or secondary airports) were identified within the metropolitan region. In addition, Table 5 displays the rank of the airport in terms of passenger traffic across 26 different countries and five world regions.

[1] Note: These multi-airport systems include; Bangkok, Dubai, Gothenburg, Istanbul, Melbourne, Mexico, Rio de Janeiro, Sao Paulo, Shanghai, Taipei, Tehran, Tel Aviv and Vancouver.

Table 5: Airport with largest passenger traffic (in 2006) in each of the 59 multi-airport systems

IATA Code	ICAO Code	Country	Airport Name	Passenger Total (millions)
ORD	KORD	United States	Chicago/O'Hare	73.9
LHR	EGLL	United Kingdom	London/Heathrow	67.3
HND	RJTT	Japan	Tokyo/Haneda	65.2
LAX	KLAX	United States	Los Angeles/Intl	58.6
DFW	KDFW	United States	Dallas/Fort Worth	57.2
CDG	LFPG	France	Paris/de Gaulle	56.8
FRA	EDDF	Germany	Frankfurt/Main	52.8
AMS	EHAM	Netherlands	Amsterdam/Schiphol	46.0
HKG	VHHH	Hong Kong Sar	Hong Kong/Intl	44.0
DMK	VTBD	Thailand	Bangkok/Don Mueang	41.0
JFK	KJFK	United States	New York/Kennedy	40.9
IAH	KIAH	United States	Houston/Intercontinental	40.5
DTW	KDTW	United States	Detroit/Metropolitan	34.6
MCO	KMCO	United States	Orlando/Intl	33.7
SFO	KSFO	United States	San Francisco/Intl	32.4
YYZ	CYYZ	Canada	Toronto/Pearson	31.0
MIA	KMIA	United States	Miami/Intl	30.9
PHL	KPHL	United States	Philadelphia/Intl	30.6
FCO	LIRF	Italy	Rome/Fiumicino	30.1
BCN	LEBL	Spain	Barcelona/Intl	29.8
DXB	OMDB	United Arab Emirates	Dubai/Intl	28.8
ICN	RKSI	Republic Of Korea	Seoul/Incheon	27.7
BOS	KBOS	United States	Boston/Logan	26.8
PVG	ZSPD	China	Shanghai/Pudong	26.6
MEX	MMMX	Mexico	Mexico City/Intl	24.6
TPE	RCTP	China	Taipei/Taoyuan	22.9
MAN	EGCC	United Kingdom	Manchester/Intl	22.1
MXP	LIMC	Italy	Milan/Malpensa	21.8
IST	LTBA	Turkey	Istanbul/Atatuerk	21.3
CPH	EKCH	Denmark	Copenhagen/Kastrup	20.8
MEL	YMML	Australia	Melbourne/Tullamarine	20.6
BWI	KBWI	United States	Washington/Baltimore	20.3
ITM	RJOO	Japan	Osaka/Itami	18.9
CGH	SBSP	Brazil	Sao Paulo/Congonhas	18.4
TPA	KTPA	United States	Tampa/Intl	18.3
OSL	ENGM	Norway	Oslo/Gardermoen	17.7
ARN	ESSA	Sweden	Stockholm/Arlanda	17.5
SAN	KSAN	United States	San Diego/Intl	17.3
YVR	CYVR	Canada	Vancouver/Intl	17.0
VIE	LOWW	Austria	Vienna/Intl	16.8
BRU	EBBR	Belgium	Brussels/Zaventem	16.6
DUS	EDDL	Germany	Dusseldorf/Intl	16.5
DME	UUDD	Russian Federation	Moscow/Domodedovo	15.4
HAM	EDDH	Germany	Hamburg/Fuhlsbuettel	11.9
TXL	EDDT	Germany	Berlin/Tegel	11.8
CLE	KCLE	United States	Cleveland/Hopkins	10.9
STR	EDDS	Germany	Stuttgart/Intl	10.0
THR	OIII	Iran	Tehran/Mehrabad	9.3
GIG	SBGL	Brazil	Rio De Janeiro/Galeao	9.3
TLV	LLBG	Israel	Tel Aviv/Ben Gurion	9.2
GLA	EGPF	United Kingdom	Glasgow/Intl	8.8
VCE	LIPZ	Italy	Venice/Polo	7.7
EZE	SAEZ	Argentina	Buenos Aires/Pistarini	7.5
BFS	EGAA	United Kingdom	Belfast/Intl	5.0
GOT	ESGG	Sweden	Gothenburg/Landvetter	4.3
CNF	SBCF	Brazil	Belo Horizonte/Neves	4.0
BLQ	LIPE	Italy	Bologna/Intl	4.0
ORF	KORF	United States	Norfolk/Intl	3.7
PSA	LIRP	Italy	Pisa/Galilei	3.0

This set of 59 multi-airport systems composed the core of the database of multi-airport systems used in the multiple-case study analysis (Table 6). Figure 57 locates these multi-airport systems worldwide. The airports located within these 59 multi-airport systems handled 50% of the total worldwide passenger traffic in 2006.

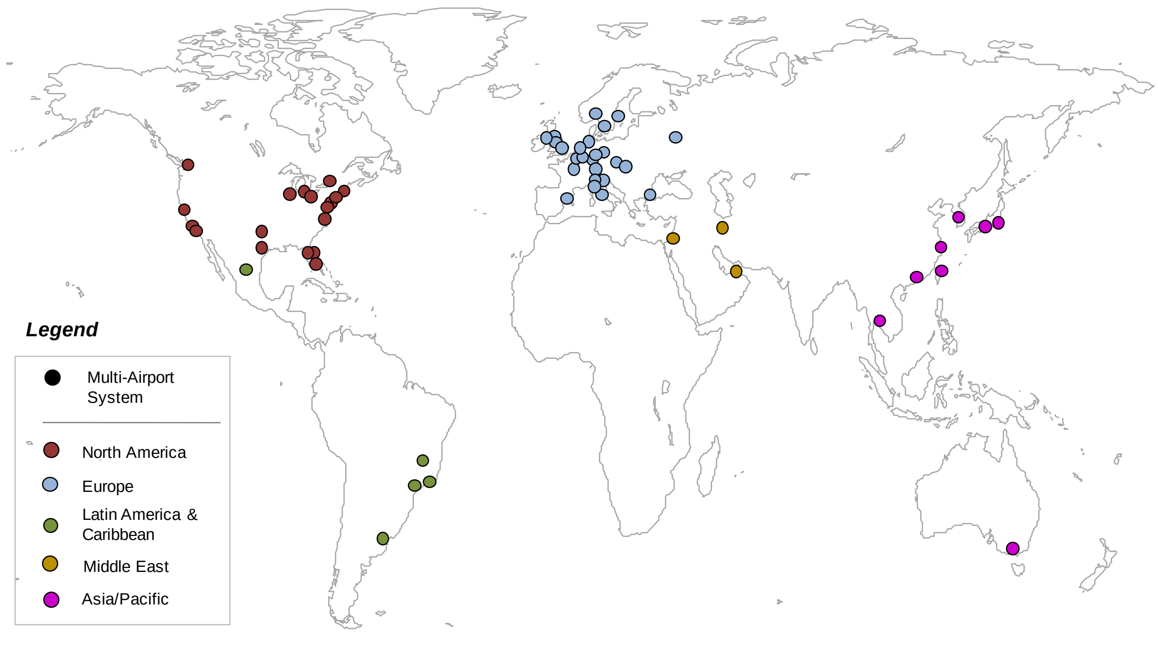


Figure 57: Geographical distribution of multi-airport systems worldwide

As shown in Figure 57, the regions of the world with the largest number of multi-airport systems are Europe and North America with 25 and 18 respectively. The third largest region in terms of number of multi-airport system is Asia-Pacific accounting for 8 systems. Then to a lesser extent, Latin America and the Middle East account for 5 and 3 multi-airport systems, respectively. Table 6 presents the distribution of primary and secondary airports across the 59 multi-airport systems.

Table 6: Set of 59 multi-airport systems worldwide[1]

World Region	Country	Metropolitan Region	Total number of significant airports	Number of primary airports	Number of secondary airports
Asia-Pacific	Japan	Osaka	3	2	1
	China	Hong Kong	2	2	0
	China	Shanghai	2	2	0
	China	Taipei	2	2	0
	Japan	Tokyo	2	2	0
	South Korea	Seoul	2	2	0
	Thailand	Bangkok	2	2	0
	Australia	Melbourne	2	1	1
Europe	United Kingdom	London	5	2	3
	Germany	Dusseldorf	4	2	2
	United Kingdom	Manchester	4	1	3
	France	Paris*	3	2	1
	Germany	Berlin	3	2	1
	Italy	Milan	3	2	1
	Russia	Moscow	3	2	1
	United Kingdom	Glasgow	3	2	1
	Netherlands	Amsterdam	3	1	2
	Spain	Barcelona	3	1	2
	Sweden	Stockholm	3	1	2
	Italy	Pisa	2	2	0
	United Kingdom	Belfast	2	2	0
	Austria	Vienna	2	1	1
	Belgium	Brussels*	2	1	1
	Danmark	Copenhagen	2	1	1
	Germany	Frankfurt	2	1	1
	Germany	Hamburg	2	1	1
	Germany	Stuttgart	2	1	1
	Italy	Bologna	2	1	1
	Italy	Rome	2	1	1
	Italy	Venice	2	1	1
	Norway	Oslo	2	1	1
	Sweden	Gothenburg	2	1	1
	Turkey	Istanbul	2	1	1
Latin America	Brazil	Sao Paulo	3	2	1
	Argentina	Buenos Aires	2	2	0
	Brazil	Belo Horizonte	2	2	0
	Brazil	Rio de Janeiro	2	2	0
	Mexico	Mexico	2	1	1
Middle East	Iran	Tehran	2	1	1
	Israel	Tel Aviv	2	1	1
	UAE	Dubai	2	1	1
North America	United States	Los Angeles	5	1	4
	United States	New York	4	3	1
	United States	Washington	3	3	0
	United States	San Francisco	3	2	1
	United States	Boston	3	1	2
	United States	Tampa	3	1	2
	United States	Miami	2	2	0
	United States	Norfolk	2	2	0
	United States	Chicago*	2	1	1
	United States	Cleveland	2	1	1
	United States	Dallas*	2	1	1
	United States	Detroit	2	1	1
	United States	Houston	2	1	1
	United States	Orlando	2	1	1
	United States	Philadelphia	2	1	1
	United States	San Diego	2	1	1
	Canada	Toronto	2	1	1
	Canada	Vancouver	2	1	1

[1] Note: The cases are presented by (1) world region by alphabetical order, (2) decreasing total number of significant airport in a region, (3) decreasing number of primary airports and secondary airports (4).
Note: Metropolitan region names with an asterisk denote regions with additional airports that serve cargo traffic (cf. Appendix B-2 for details on the list of airports).

The airports in the 59 multi-airport systems were divided into two main categories based on airport passenger traffic share within the multi-airport system. Figure 58 shows the distribution of passenger traffic share across the 144 airports in the analysis. Primary airports (86) accounted for 60% of all airports in the study, secondary airports (58) accounted for 40%.

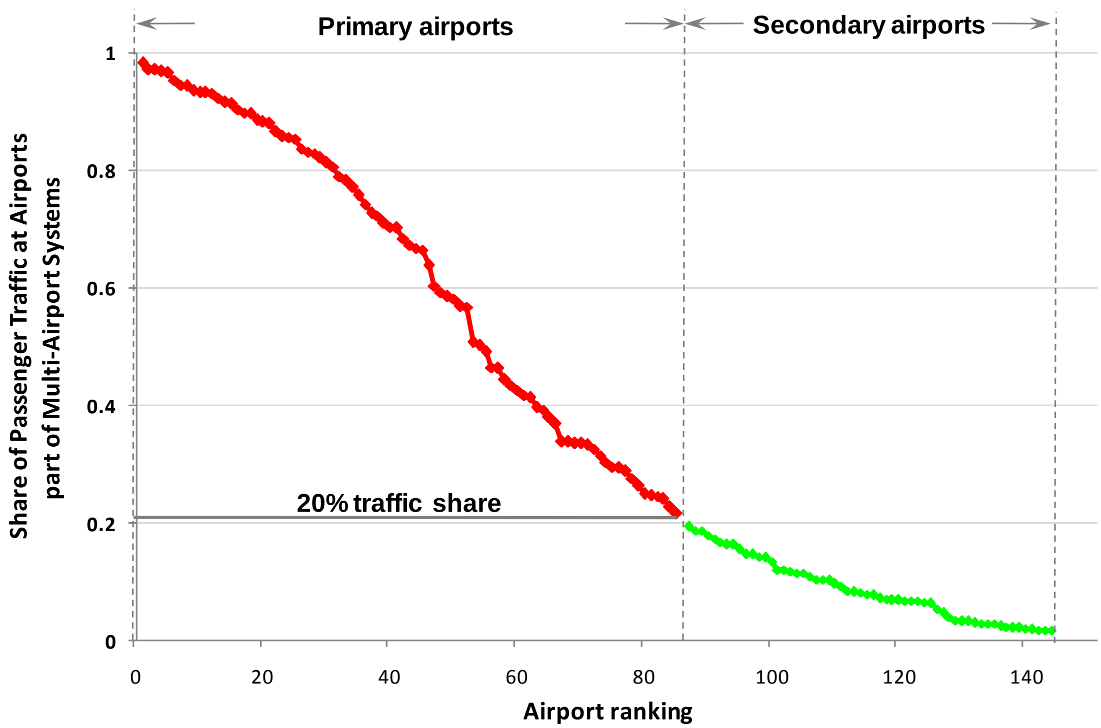


Figure 58: Share of passenger traffic at airports part of the 59 multi-airport systems (ranked by decreasing share)

Table 7 shows the distribution, by world regions, of primary and secondary airports part of multi-airport systems[1]. The multi-airport systems in Europe, North America, Middle-East and Africa, tend to exhibit balanced distribution of primary and secondary airports, whereas in Asia-Pacific and Latin America a larger fraction of the airports are primary airports.

[1] Note: The lists of airports (i.e. primary and secondary airports) that are part of multi-airport systems are presented in Appendix B-1.

Table 7: Distribution of primary and secondary airports within the 59 multi-airport systems (by world region)

World region	Number of	
	primary airports	secondary airports
Europe	34	31
North America	25	20
Asia-Pacific	16	2
Latin America	9	2
Middle East	3	3

As Table 6 and Table 8 show, there are several types of multi-airport systems (i.e. number and combinations of airports). The most frequent type of multi-airport system is composed of two airports; a primary and a secondary airport (e.g. Chicago, Frankfurt, and Melbourne) or in some cases two primary airports (e.g. Miami, Belfast, Shanghai). The systems become more complex as the number of primary and secondary airports increases. The most complex multi-airport systems are Los Angeles (with 1 primary and 4 secondary), London (with 2 primary and 3 secondary) and New York (with 3 primary and 1 secondary).

Table 8: Configurations of multi-airport systems (combinations of primary and secondary airports)

Number of secondary airports \ Number of primary airports	0	1	2	3
4	N/A	**Los Angeles**		
3	N/A	**Manchester**	**London**	
2	N/A	**Amsterdam, Barcelona, Stockholm, Boston, Tampa**	**Dusseldorf**	
1	N/A	**Bologna, Brussels, Cleveland, Chicago, Copenhagen, Dallas, Detroit, Dubai, Frankfurt, Gothenburg, Hamburg, Houston, Istanbul, Melbourne, Mexico, Orlando, Oslo, Philadelphia, Rome, San Diego, Stuttgart, Tehran, Tel Aviv, Toronto, Vancouver, Venice, Vienna**	**Osaka, Paris, Berlin, Milan, Moscow, Glasgow, Sao Paulo, San Francisco**	**New York**
0	N/A	*Single Airport Systems*	**Hong Kong, Shanghai, Taipei, Tokyo, Seoul, Bangkok, Pisa, Belfast, Buenos Aires, Belo Horizonte, Rio de Janeiro, Miami, Norfolk**	**Washington**

The following section and chapter presents a detailed analysis of the dynamics that govern the evolution of multi-airport systems. This analysis provides the explanations for the observed differences in the nature and distribution of primary and secondary airports across world regions.

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CHAPTER 7

PATTERNS OF EVOLUTION OF MULTI-AIRPORT SYSTEMS

The set of 59 multi-airport systems presented in Chapter 6 formed the basis for the multiple-case study analysis. The following chapter presents the results of the analysis of the patterns of evolution of these multi-airport systems. In the first part of this chapter, transition diagrams of the spatial configurations of the multi-airport are presented as a basis for the analysis. The following section presents the results of the multiple-case study analysis.

7.1 Transition Diagram of Spatial Configurations of Multi-Airport Systems

The identification of multi-airport systems relied on a cross-sectional analysis. This analysis showed the diversity of the configurations of multi-airport systems (i.e. combination and distribution of primary and secondary airports). It motivated the need to investigate the temporal evolution of these systems and identify the mechanisms that governed their evolution. In order to analyze the patterns of evolution of multi-airport systems, a time series analysis was performed. This time series analysis was based on passenger traffic data from ICAO[1], FAA[2] and airport reported data for the years 1975 to 2006 and additional data gathered throughout the analysis of the history of airports (cf. Appendix C for details and evidence for each case).

For the purpose of this time-series analysis, airports within multi-airport systems were categorized based on their role and evolution in the system. Four categories of airports were observed:

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[1] Data source: International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008.

[2] Data source: Federal Aviation Administration, "Terminal Area Forecasts, (historical records)", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: 2007.

- ***Original primary airport:*** It was defined as the significant initial airport serving the metropolitan region[1].
- ***Emerged primary airport:*** An airport that emerged while an original primary airport was already serving the metropolitan region. These airports can be the result of the construction of a new airport with transfer of traffic. They can also result from the growth of traffic at a secondary airport that exceeds 20% of the passenger traffic in the metropolitan region.
- ***Emerged secondary airports:*** An airport serving between 1% and 20% of the total passenger traffic served in the multi-airport system (and serving more than 500,000 passengers per year) and that emerged from the utilization of under-utilized airports available in the metropolitan region.
- ***Secondary airport that was historically an original primary airport:*** Airport that meet the secondary airport criterion[2] but was formerly an original primary airport. At some point in time this airport lost traffic (i.e. generally through the process of transfer of traffic to a newly constructed airport) and became a secondary airport.

This time series analysis resulted in the identification of fundamental patterns of evolution of multi-airport systems airports that are presented in Table 9. Actual patterns of evolution of traffic for each of the multi-airport systems are presented in Appendix C along with historical evidence of the major changes that occurred at these airports.

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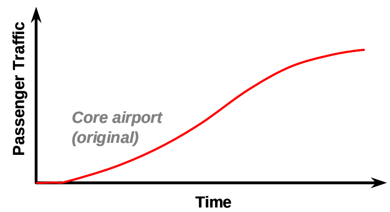
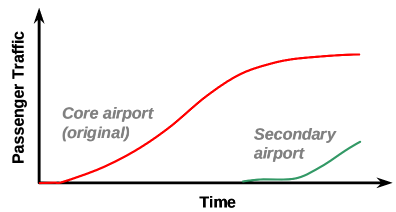
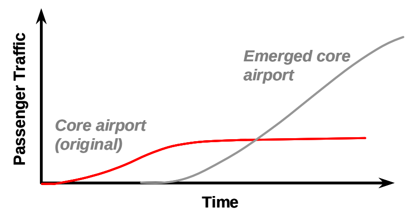
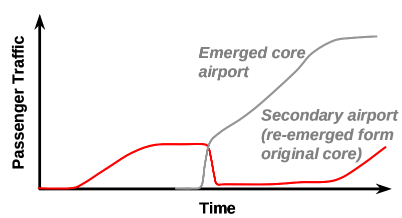
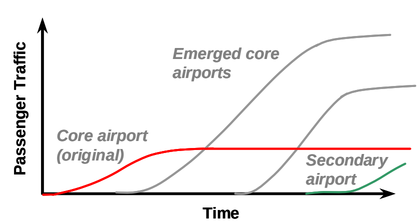
[1] Note: For the purpose of this research and for the analysis of the evolution patterns of multi-airport systems, the initial airport serving a metropolitan region was identified as of 1940, or later in the case where the initial primary airport was closed.
[2] Note: An airport serving between 1% and 20% of the total passenger traffic served in the multi-airport system (and serving more than 500,000 passengers per year).

Table 9: Fundamental patterns of evolution of traffic within multi-airport systems

Type of regional airport system	Combinations of airport types	Traffic evolution patterns
I	Single primary airport (original)	
II	Primary airport (original) & Secondary airport	
III	Primary airport (original) & Emerged core airport	
IV	Emerged primary airport & Secondary airport (Re-emerged from original core airport)	
V	Combination of: Primary airport (original), Emerged primary airport & Secondary airport	

Based on these time series and historical analyses, two fundamental evolutionary mechanisms were identified;

- ***Construction of new airports***, (with full or partial transfer of traffic),
- ***Emergence through the use of existing airport*** (without restriction of initial role; civil or military).

The diagram presented in Figure 59 represents the fundamental evolutionary paths along which airport systems evolve.

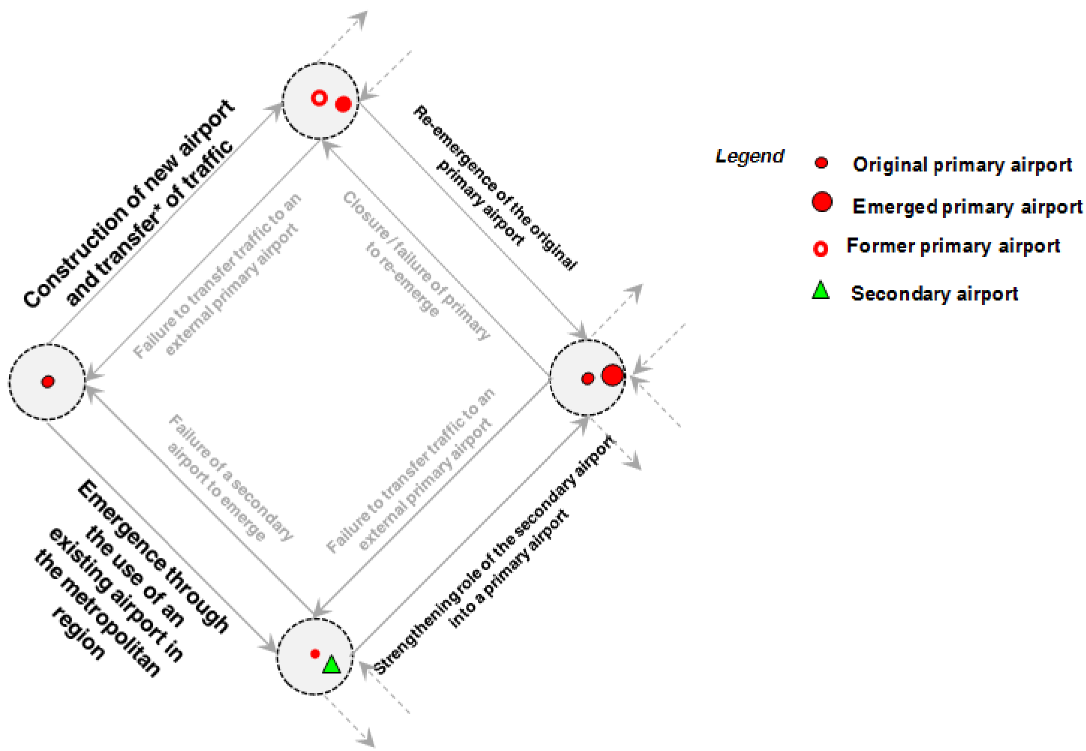


Figure 59: Conceptual transition diagram of spatial configurations of multi-airport systems (i.e. single airport to two airport systems)

As shown on Figure 59, a single airport system can transition to a multi-airport system through the construction of the new airport in the region and with partial or total transfer of traffic (i.e. upper path on Figure 59). Another possible evolution path that can lead the system to become a multi-airport system is through the use of existing airports in the metropolitan region. In this case, there is an evolution by utilization of existing resources that were not previously utilized. From this state, the system can continue to evolve by the addition of new airports or the emergence of existing airports.

7.2 Patterns of Evolution of Multi-Airport Systems: Results from the Multiple-Case Study Analysis

In order to analyze the patterns of evolution of the multi-airport systems by world region, the conceptual transition diagram of spatial configurations of multi-airport systems was used. For each of the 59 multi-airport systems, the transitions were identified through the analysis of the historical evolution of passenger traffic and evidence of historical events that influenced the role of each airport. These pieces of evidence were gathered throughout the multiple-case study analysis (cf. details on evidence of evolution and transition of multi-airport systems cases are presented in Appendix C).

Table 10 and Figure 60 show the frequency of occurrence of both types of the transitions by world region.

Table 10: Frequency of occurrence of fundamental mechanisms that governed the evolution of multi-airport systems by world-regions[1]

World region	Fundamental mechanism that govern the evolution of multi-airoprt systems: Emergence of secondary airport through the use of an existing airport	Construction of a new airport
Europe	81%	19%
North America	81%	19%
Middle East	50%	50%
Latin America	20%	80%
Asia/Pacific	10%	90%

Multi-airport systems in *North America* and *Europe* have predominantly evolved through the emergence of existing under-utilized airports. It was also found that these multi-airport systems either evolved solely through the emergence of airports (i.e. from the utilization of existing airports) or through first the construction of a new airport and then subsequent emergence of existing airports. In all cases, the construction of a new airport is an older phenomenon in North America and Europe (e.g. Chicago/O'Hare, Dallas/Fort Worth, Houston/Intercontinental and Paris/de Gaulle). The construction of airports in these cases occurred primarily in the 1960s and 1970s, mostly because the

[1]Note: Middle-East only accounts for 3 multi-airport systems and the results are not necessarily statistically significant. However, recent trends in construction of new high capacity airports, such as the Dubai World Trade Centre (DWTC) and other projected airports in the region tend to confirm this finding.

original airports were limited by runway lengths that could not accommodate wide-body jets (Figure 61). The emergence of secondary airports from the utilization of existing airports in these regions is a much more recent phenomenon (i.e. mostly due to the emergence and growth of low-cost carriers).

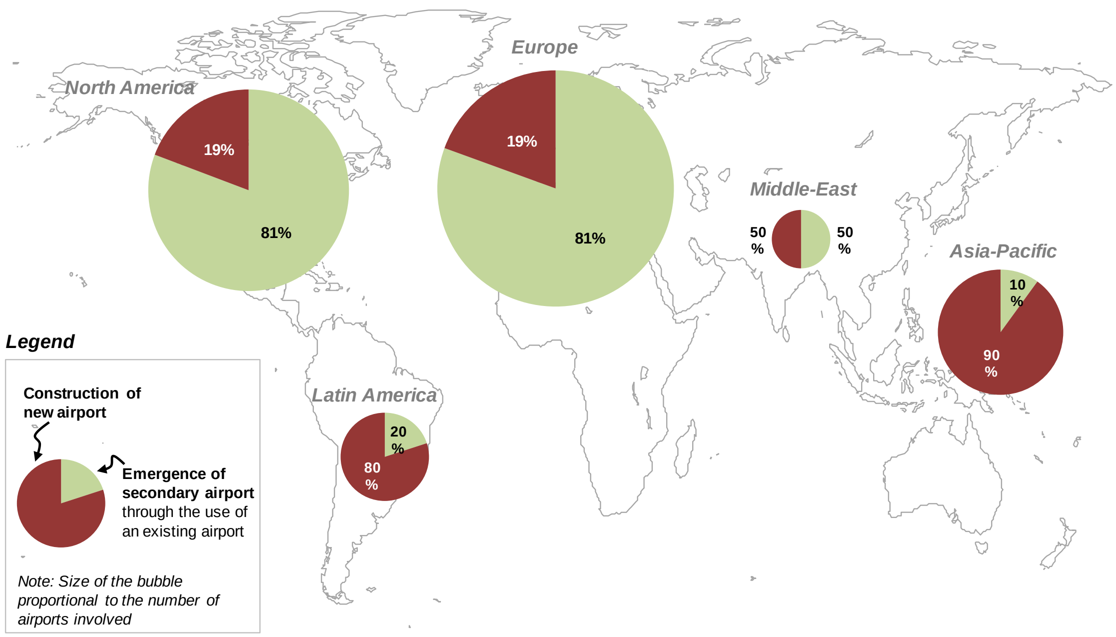


Figure 60: Frequency of occurrence of fundamental mechanisms that governed the evolution of multi-airport systems by world-regions

Multi-airport systems in *Latin America* and *Asia-Pacific* have predominantly evolved through the construction of new airports. In *Latin America*, new airports were constructed in the 1940s and 1970s. For the two airports built in the 1970s, the same reason that motivated airport construction in Europe and North America prevailed (i.e. original primary airports were limited by runway lengths and could not accommodate wide-body jets). While multi-airport systems in *Asia-Pacific* have evolved predominantly through the construction of large primary airports[1] with partial transfer of traffic to the new primary airport, these airports were built more recently (i.e. mostly in the 1990s and 2000s). These airports were built due to congestion of the primary airports and forecast of future demand.

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[1] Note: The only case of emergence of secondary airport in the Asia-Pacific region was identified in Melbourne, Australia (i.e. Melbourne/Avalon) where it serves low-cost carriers.

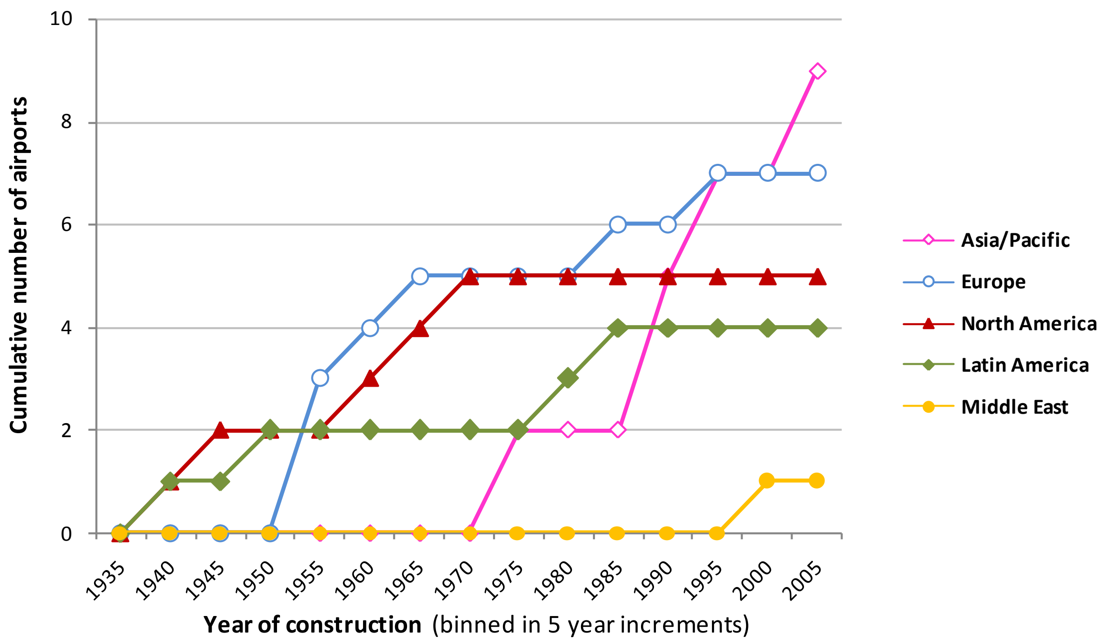

Figure 61: Cumulative number of airports by year of construction (i.e. new airports within the 59 multi-airport systems)

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CHAPTER 8

DYNAMICS AND FACTORS INFLUENCING THE EVOLUTION OF MULTI-AIRPORT SYSTEMS

In order to better understand and explain the differences in the evolution of multi-airport systems (i.e. emergence of airports from non-utilized airports versus construction of new airports), a detailed analysis of the dynamics and factors influencing the evolution of multi-airport systems was performed. This analysis was largely based on a multiple-case study analysis of the 59 multi-airport systems (i.e. cases) presented in Chapter 6.

8.1 Feedback Model of the Evolution of Multi-Airport Systems

8.1.1 Methodology

To frame and summarize the dynamics and factors that influenced the evolution of multi-airport systems, a feedback model was developed. Figure 62 shows the general representation of the model.

The development of the model, the multiple-case study analysis, layout the causal relationships between the dynamics (i.e. processes or chain of processes) and the factors that influence these dynamics, were based on literature on case study research methods (Yin, 1994), and quasi-experimental research methods (Blalock, 1961). In addition, the modeling principles are based on system dynamics (Sterman, 2001) and process modeling.

For each case (i.e. one case being defined as one multi-airport system), the set of primary and secondary airports was identified. A geographical analysis was performed to evaluate the location of each airport relative to the center of the metropolitan area (i.e. primary city) and secondary basins of population. An analysis of the historical evolution of traffic was also performed using FAA[1], ICAO[2] and airport reported traffic data. Using

[1] Data source: Federal Aviation Administration, "Terminal Area Forecasts", (historical records), available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: 2007.
[2] Data source: International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008.

a large set of sources[1] (i.e. airport websites, airport authority annual reports and websites, industry and trade group publications), a historical analysis of the key events that affected the evolution of individual airports was performed.

The following section presents an overview of the model and its key components (i.e. processes or set of processes). Then the model is presented in detail, highlighting the sub-dynamics and the factors that influence sub-dynamics of the emergence of secondary airports (Figure 69) and the construction of new airports (Figure 92).

8.1.2 Overview of the feedback model

The model captures *sets of processes*, *physical components* of the air transportation system (i.e. airports), and *performance metrics*.

The model is arranged so that the *sets of processes* (i.e. passenger demand, airline sector, regulatory sector, local and regional governments, infrastructure investment groups, airport operators and airport planners and developers) are presented on the left side.

These processes modify the state of the *physical components* of the system (i.e. airport systems) that are represented in the middle section of the model. For the purpose of this research, these are divided into four sets; (1) *primary airport*, (2) *secondary airport* and (3) *new airport*, and also a larger (4) set of *existing non-utilized airports in the metropolitan region*.

Following the similar representation that was used in Figure 3, the *performance metrics* of these systems are represented on the right hand side of the system components. These performance metrics (e.g. delays, externalities, fares, destinations, etc.) that combine into *airport attractiveness to airlines* and *passengers*, *pressure to reduce delays* and *regional economic impacts*, are then used as input to the processes described on the left hand side of the model.

The chain composed by these *processes*, *systems components* and *performance metrics* form feedback loops. Theses feedback loops capture the two fundamental

[1] Note: The sources of pieces of evidence gathered throughout the case study analysis are presented in the Appendix C (i.e. for each case of multi-airport system and individual airports that compose these systems).

dynamics that affect the evolution of multi-airport systems; the *construction of new airports* and the *emergence of secondary airports from existing underutilized airports*.

Previous work by Bonnefoy and Hansman that consisted of the development of a system dynamics model of the dynamics affecting the emergence of secondary airports in the United States (Bonnefoy, et al., 2005) formed a preliminary version of this model. The model was then iteratively expanded and refined using the multiple-case study analysis of the 59 existing multi-airport systems worldwide presented in Chapter 6.

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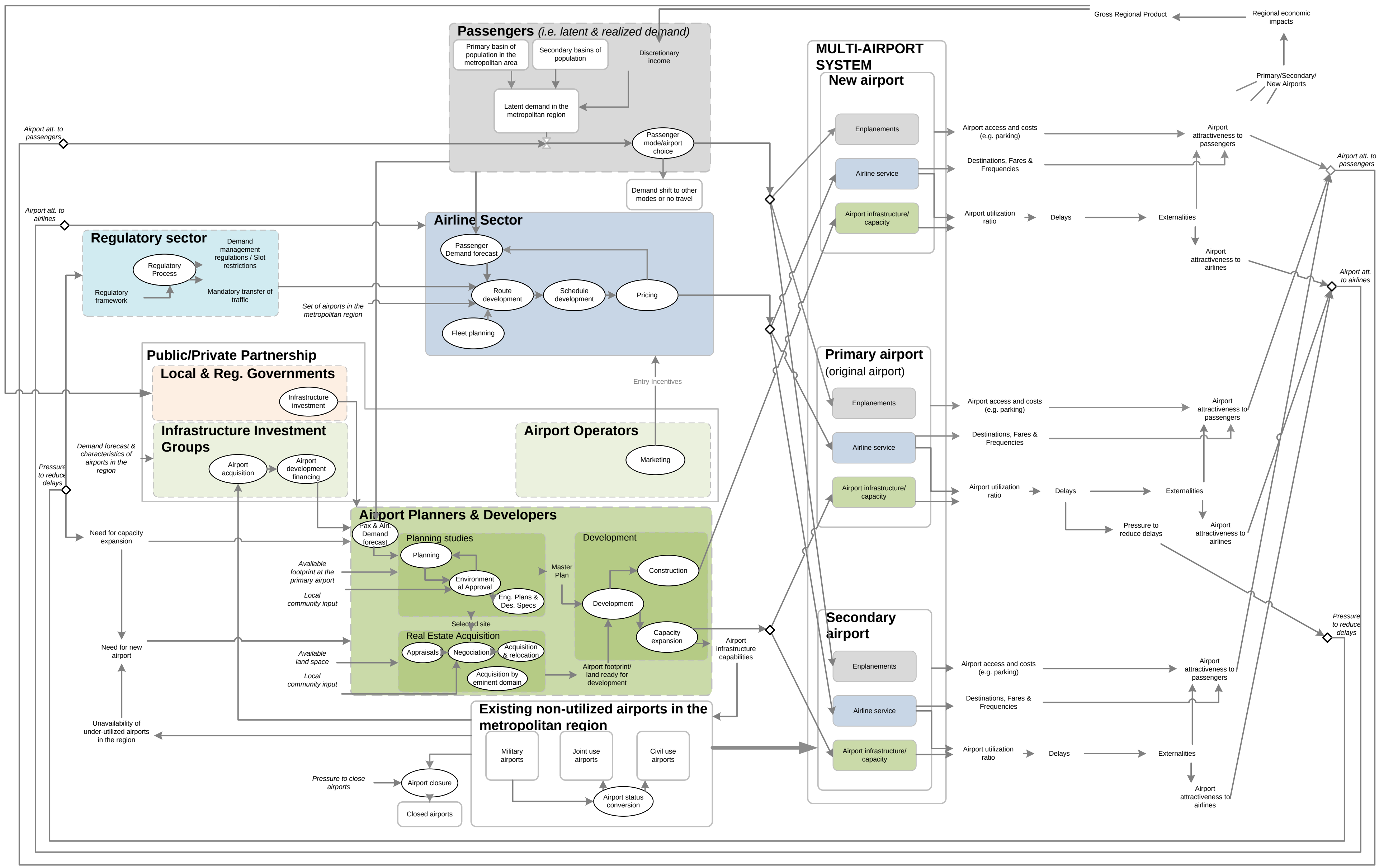

Figure 62: Feedback model of the evolution of multi-airport systems

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8.1.3 Detailed description of key processes in the feedback model

The model captures *sets of processes* that affect the state of the airport systems. These processes are divided into 7 sets of processes that are named after the main stakeholders involved in these processes; (1) *passengers (i.e. latent and realized demand)*, (2) *airline sector*, (3) *regulatory sector*, (4) *local and regional governments*, (5) *infrastructure investment groups*, (6) *airport operators* and (7) *airport planners and developers*.

a. Passengers (i.e. latent and realized demand)

The decomposition of the air transportation system presented in Figure 4, into demand, passenger, airlines and airport infrastructure is reflected in the layout of the feedback model. The passenger and demand layers of the system have been merged into one set of processes and system attributes. The "*passengers (i.e. latent & realized demand)"* box captures the attributes that generally underlie the generation of demand for transportation (i.e. population distribution, socio-economic factors such as discretionary income). It also captures the key processes that influence how demand for air transportation is distributed across airports within the metropolitan region (i.e. mode choice).

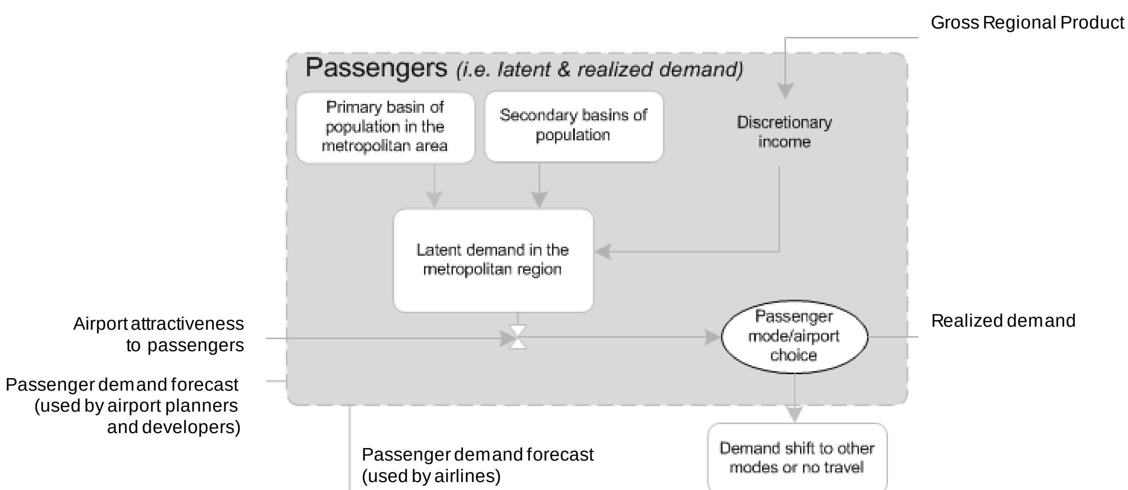

Figure 63: Passenger (latent and realized demand) component of the model

By definition, latent demand is the demand for a product or a service if the market is served efficiently[1]. Generally, latent demand is greater than realized demand. In the case of the air transportation system, latent demand can be seen as the total number of trips that passengers would be willing to take per unit of time (e.g. in one month or in one year) if service was provided efficiently[2] from an economic stand point (i.e. produced with the minimum amount of waste or the maximum output for given inputs and technology).

As represented Figure 63, latent demand for air transportation is directly influenced by population size and distribution in the metropolitan region and socio-economic factors (i.e. discretionary income allocated to travel) that influence this demand.

The supply of air transportation services (i.e. airport attractiveness for passengers) is then used as an input to the *passenger mode/airport choice.* The resulting output of this process is *realized demand* that is distributed among the set of airports in the region. The demand that has not been assigned to air transportation can be diverted to other modes of transportation or just not be realized.

b. Airline sector

The *airline sector* is represented by a set of key processes that capture the decision making process of airlines. The decisions made by airlines result in service offerings across the different airports in the metropolitan region. The airline decision making process, with regard to the service offering, is generally composed of a multi-step process that spans from the strategic to operational levels (Barnhart, 2003). Demand on routes is assessed based on a passenger demand forecast that is taken into account in the route development (based on available resources; aircraft fleet, crews, etc.). Then a schedule is developed, followed by pricing. The final output of this set of processes is the provision of flights across the set of airports in the metropolitan region. The choice of airports to

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[1] Note: In a more precise version of the definition of latent demand, it is defined as industry earnings of a market when that market becomes accessible and attractive to serve by competing firms. It is a measure of potential industry earnings (P.I.E.) or total revenues (not profit) if a market is served in an efficient manner.
[2] Note: Economic efficiency implies that; (1) no one can be made better off without making someone else worse off, (2) the most output is obtained from a given amount of inputs and (3) production proceeds at the lowest possible per unit cost.

serve in a region is also driven by high level strategic and business models (cf. low-cost carrier entries in section 8.3).

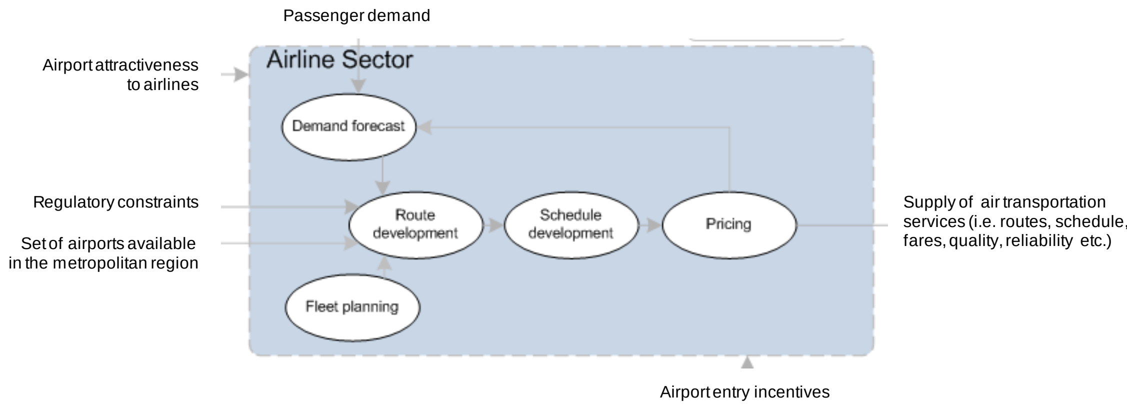

Figure 64: Airline sector component of the model

c. Airport sector

The processes that affect airport infrastructure are captured in the *airport planners and developers* and the *existing non-utilized airports in the metropolitan region* boxes. Figure 65 shows the processes that affect airport infrastructure and that result in capacity expansion and construction of new airports.

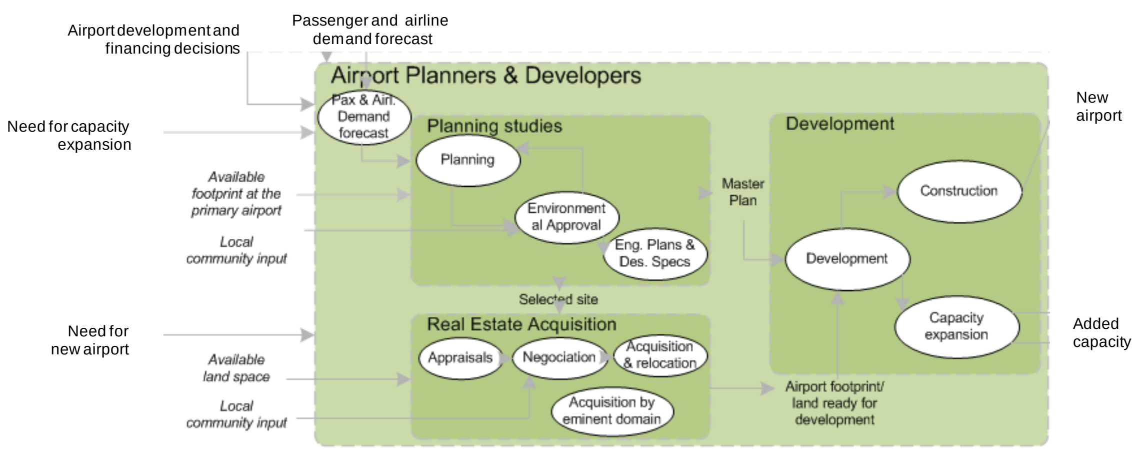

Figure 65: Airport planning and development component of the model

The general planning and development process of airport is composed of *planning studies*, *real estate acquisition* and *development*. The *planning studies box* is composed of a sequence and iterative processes; planning, environmental approval, engineering plans and design specifications. This phase of the process is influenced by forecasts (i.e.

passengers and airline traffic), financing, existing airport characteristics (i.e. airport footprint) and available land space for the case of the construction of a green field airport. The output of this process is a generally a master plan. In the case of the construction of a green field airport, the output of this process is a decision with regard to the selection of a site.

The decision of the selection of a site serves as input to the *real estate acquisition* process. There are generally two tracks in this process, the *appraisal*, *negotiation* and *acquisition* track and the *acquisition by eminent domain track.*

The development process is only presented here at a high level of description, showing the two cases of development that are of importance for this research; *construction* of green field airports and *capacity expansion* of existing airports.

Existing non-utilized airports in the metropolitan region

The airport sector processes is also composed of processes affecting existing non-utilized airport in the metropolitan region. There are two key processes affecting this set of airports; (1) *airport status conversion* by which military airports can be transformed into joint use or civil use airports, and (2) *airport closure*.

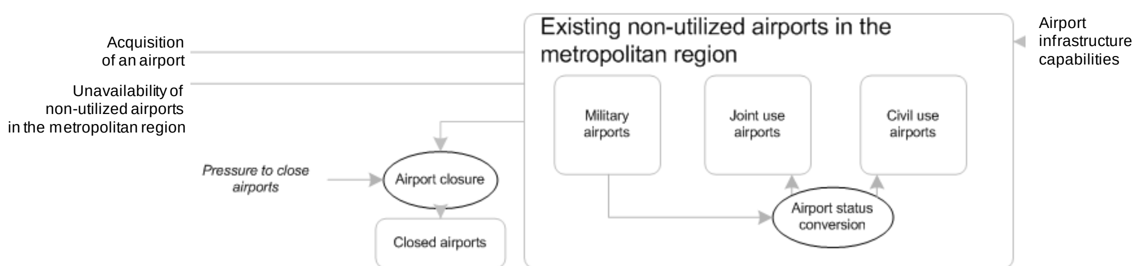

Figure 66: Component of the model representing the set of existing non-utilized airports in a metropolitan region with associated processes

d. *Regulatory sector*

The *regulatory sector* is represented specifically for its influence on the airlines and airport management through the provision of regulations that impose *demand management (e.g. slot restrictions)* or *mandatory transfer of traffic*.

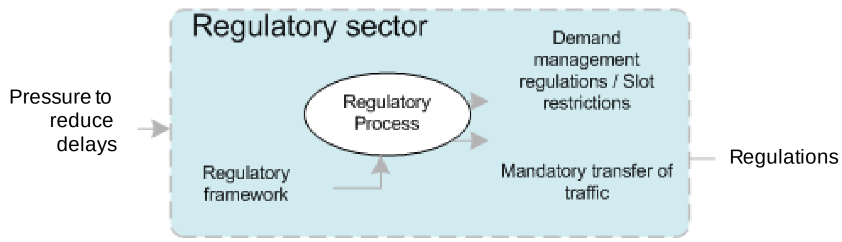

Figure 67: Regulatory sector component of the model

e. *Infrastructure investment component*

For the purpose of this research, the *infrastructure investment components* are represented by the *local and regional governments* and *infrastructure investment groups* for their role in the acquisition and financing of airports.

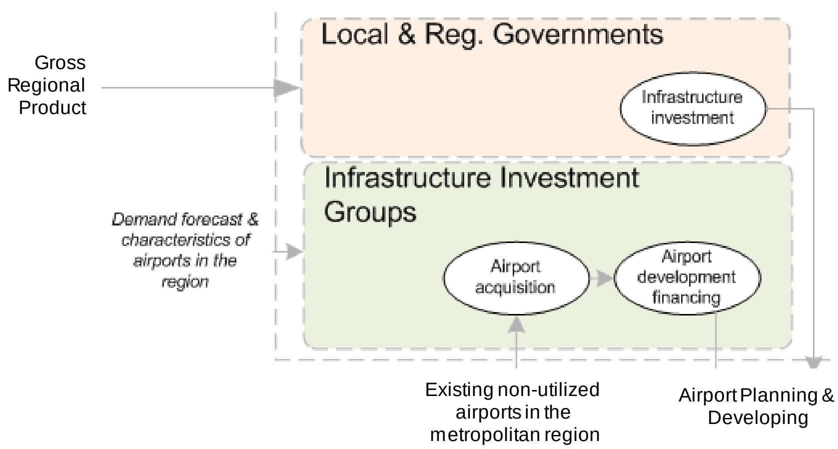

Figure 68: Infrastructure investment component of the model

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8.2 Dynamics and Factors Influencing the Emergence of Secondary Airports

8.2.1 Brief description of the model

As shown on Figure 59, multi-airport systems can evolve either through the emergence of secondary airports by using existing non-utilized airports or though the construction of new airports with transfer of traffic.

The emergence of secondary airports is influenced by a subset of sub-dynamics and factors. First, this mechanism assumes the availability of airport infrastructure in the metropolitan region. Those can originate from civil airfields or military airfields converted into civil or joint use airports. Second, the emergence of a secondary airport requires one or more airlines to start offering service at an under-utilized airport. These decisions are generally motivated by projections of demand to stimulate and/or congestion of the primary airports that make the secondary airport attractive compared to the primary airport. This dynamic of secondary airport is also influenced by secondary factors such as; incentives to airlines to offer service at an airport.

The following section presents the detailed dynamics and factors that govern the evolution of multi-airport systems through this path of emergence of secondary airports.

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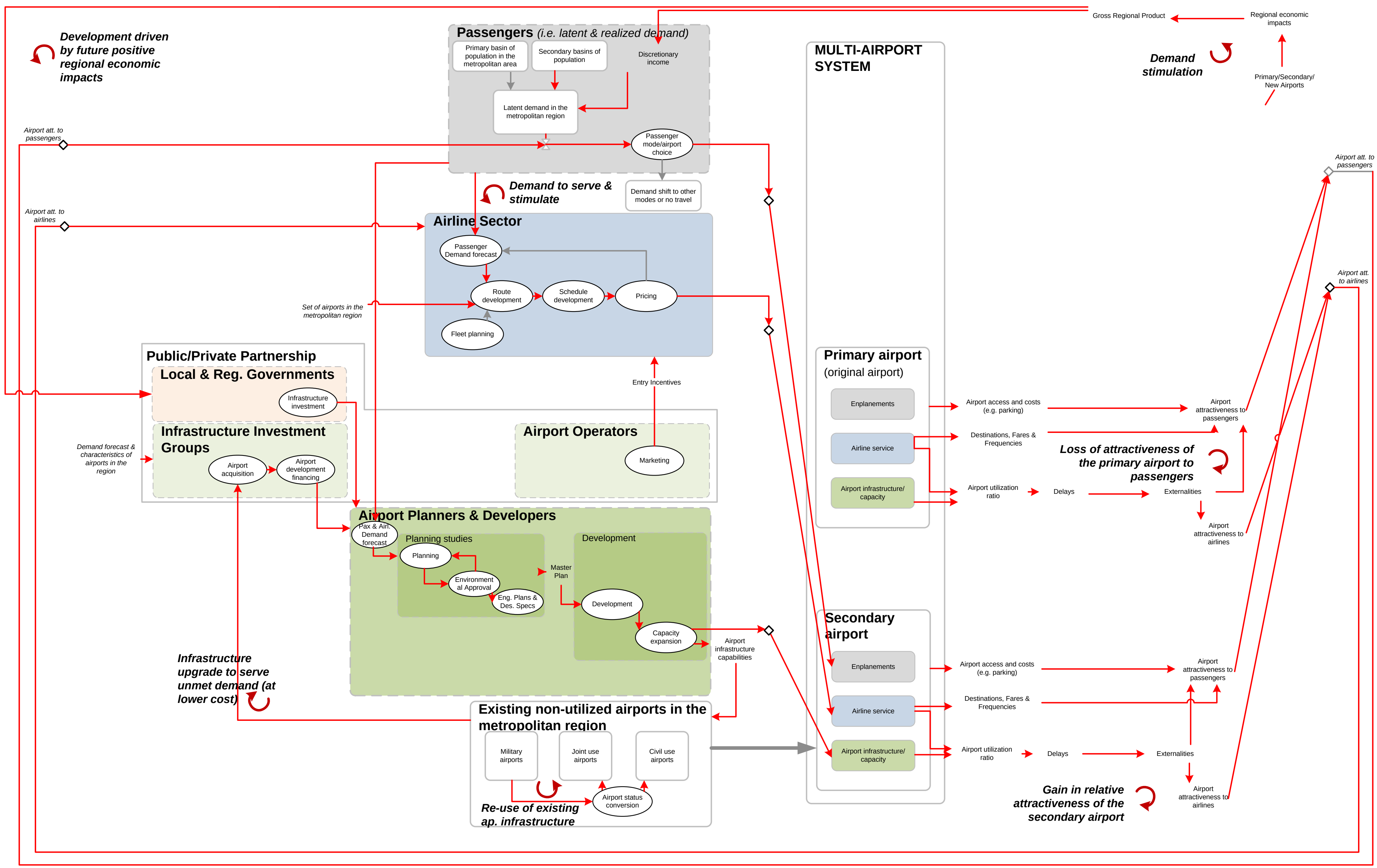

Figure 69: Feedback model of the dynamics and factors that influence the emergence of secondary airports

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a. Sub-dynamics

- ***Entry of carriers (e.g. low-cost carriers)***

Figure 69 shows the airline decision making processes involved in the entry and provision of service at an airport. The route development process is based on a demand forecast for origin-destinations and availability of aircraft (i.e. fleet planning). Then a schedule is developed followed by pricing. This process is generally iterative. The route development process is the key process during which an airline can decide to provide service at a secondary airport. As represented in the model, this process is influenced by the attractiveness of the airport to airlines, which is defined as a function of key factors such as projected demand, delays at the primary airport, cost of operation at the secondary airport and whether the airline already offers traffic at the primary airport.

Role of demand stimulation on the emergence and growth of secondary airports;

The entry of new carrier offering service at low fares can attract passengers who were previously using the primary airport and/or stimulate demand in the region and generate new traffic within the region.

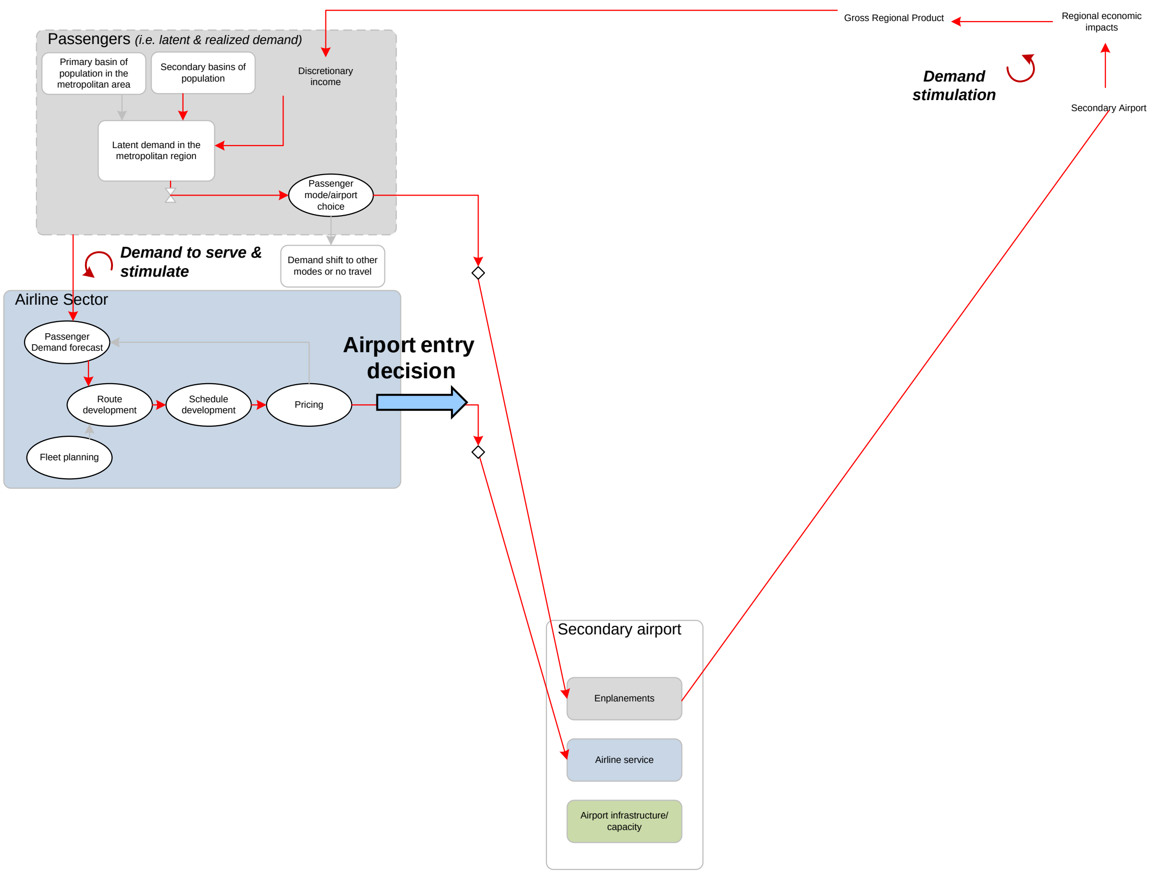

Figure 70: Feedback loop illustrating the role of demand stimulation on the emergence and growth of secondary airports

There are two cases to distinguish regarding the entry of a low-cost carrier at a secondary airport; (1) the airport was already served by carriers with very limited service and high fares, (2) the airport had no air carrier service. In the case where the airport had no service, the entry of a new carrier competes with carriers serving other airports in the metropolitan region. In the case where service existed at the secondary airport, the new carrier competes with carriers at the secondary and other airports in the region.

Figure 71 shows the impact of the entry of a low-cost carrier into a market. These dynamics are valid for competition within the original OD pair market, on semi-parallel OD markets or parallel markets (cf. parallel network description in Chapter 5). After the entry of a low-cost carrier, the average yield (i.e. revenue per passenger mile) decreases, demand is stimulated and passenger traffic increases (cf. Model, Figure 69, *Demand to* *stimulation* and *demand to serve and stimulate* loops). This phenomenon is also referred to as the "Southwest effect" (Bennett, et al., 1993).

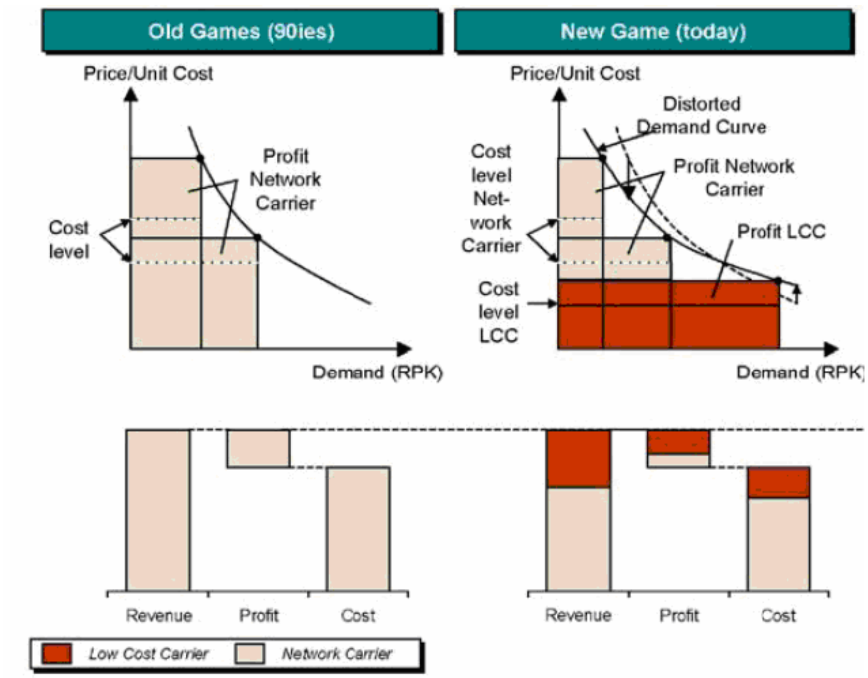

Figure 71: Economic model for low-cost carriers [Source: (European Parliament, 2007)]

<u>Subsequent entries of carriers at secondary airports;</u>

The entry of a specific carrier and the drop of air fares are not the only changes in the dynamics of the secondary airport. Following the successful entry of the new carrier (i.e. generally a low-cost carrier) several other carriers may enter service at the secondary airport. These are attracted by profit sharing on the markets and given that these airports are under-utilized airports, there are no or lower barriers of entry than at primary airports. Primary airports can also be slot restricted, which constitute high barriers of entry. These airports are also generally exhibiting high level of delays and also offer much higher costs of operation than at the secondary airports.

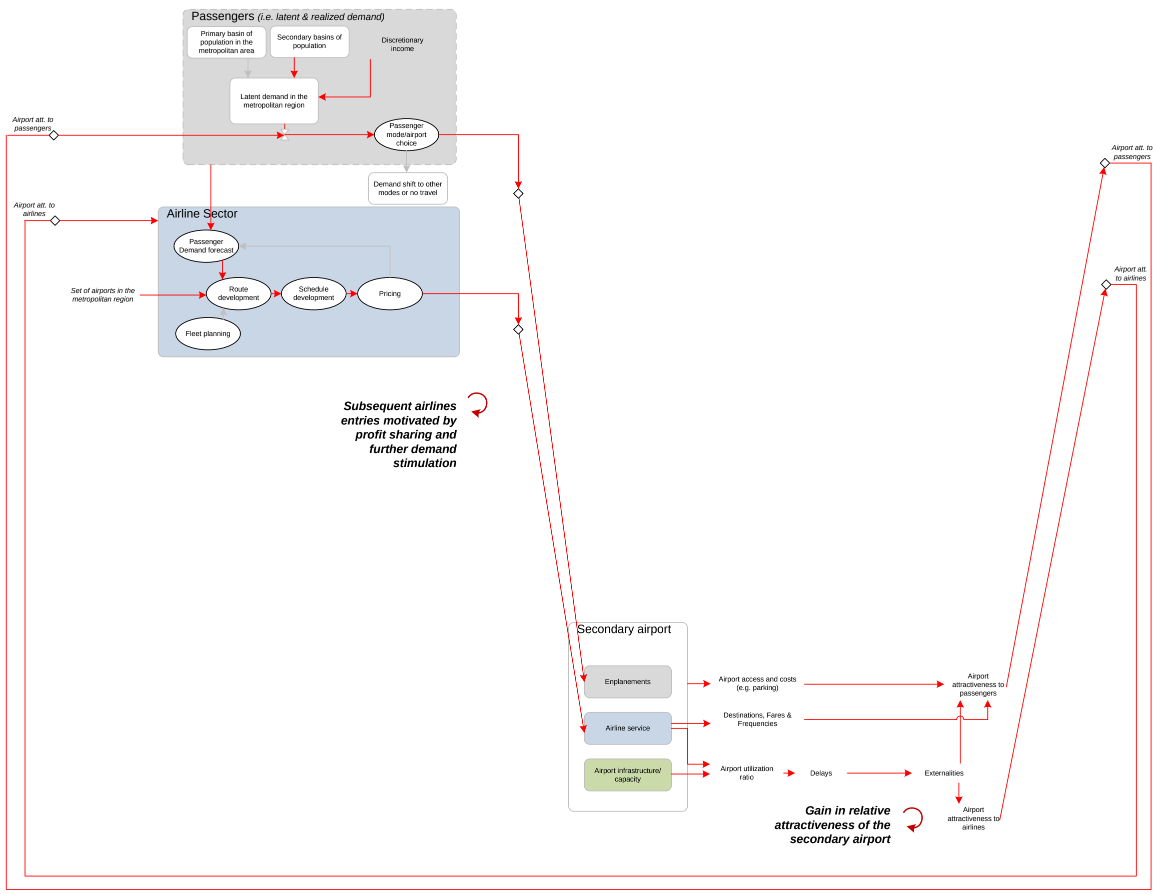

Figure 72: Feedback loop dynamics of subsequent entries of carriers

- ***Changes of airport status; conversion from military to civil status***

The entry of a new carrier at secondary airports assumes the availability of usable airports in the metropolitan region. As shown on Figure 69, new secondary airports can originate from the set of civil use airports available in the region (cf. Model, Figure 69, *re-use of existing airport infrastructure* loops). Other sources of existing airports are joint use and military airports that can be converted.

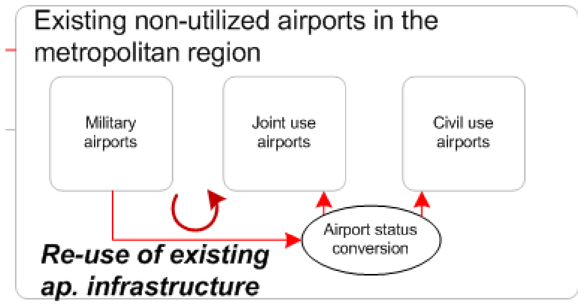

Figure 73: Process of airport status conversion

- ***Upgrade of airport infrastructure***

In order to host new service by entrant carriers, the airport must exhibit certain characteristics. The most discriminating factor of usability of airports is the length of the runways which dictates the types of aircraft that can be used. Figure 74 shows the balanced field length requirements for a set of popular aircraft. Wide body jets typically require 7000 to 10,000 ft runways. For smaller aircraft, runway length requirements are lower. Narrow body jets can operate at airports with runway lengths from 5300 to 6900 ft. Even though regional jets carry fewer passengers than narrow body jets, they have similar requirements due to the characteristics of their propulsion system. Turbo-props can operate at airports with smaller runways, typically from 3500 to 4500 ft.

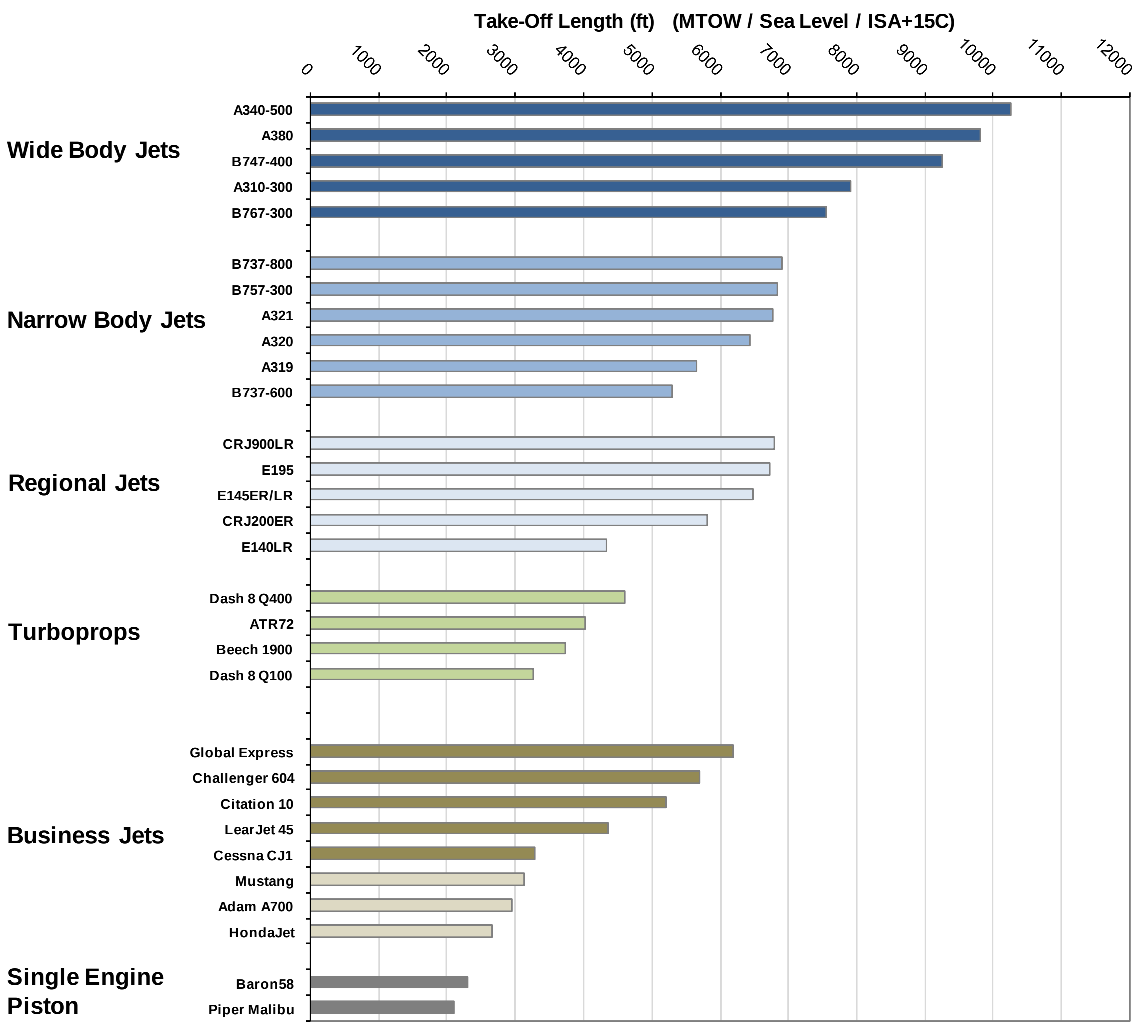

Figure 74: Take-off field length requirements for six aircraft categories

As a result, the emergence of an under-utilized airport can require runway infrastructure expansion to serve aircraft generally used by low-cost carriers (i.e. Boeing 737s and Airbus A320s). Similarly, the construction of new terminals can be required. These developments do not necessarily require large investments (i.e. especially compared with investments performed at major airports). In addition, some airports can develop service offerings that are tailored to low-cost carriers resulting in the development of low-cost airports (de Neufville, 2007).

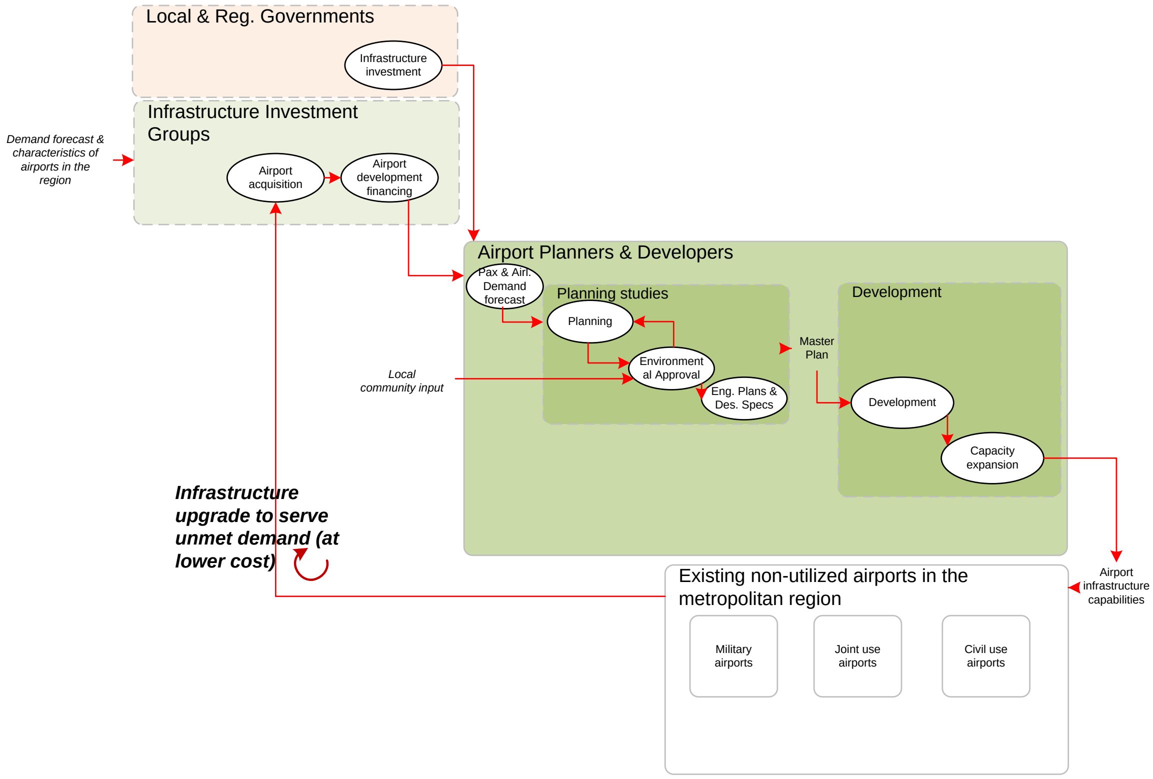

Figure 75: Feedback loop representing the dynamic of upgrade of non-utilized airport infrastructure

b. Factors influencing the emergence of secondary airports

The dynamics of emergence of secondary airports are also influenced by a wide range of factors.

- ***Availability of airport infrastructure in the metropolitan region***

Given that the emergence of secondary airports relies on the availability of existing airports in the metropolitan region, the larger this set is, the higher the probability that one of these airports is located appropriately (cf. close to a secondary basin of population, connected to ground transport network) and could become a successful secondary airport.

For the purpose of this research, regional airport system capacity coverage plots were constructed in order to evaluate the availability and distribution of existing airports in a region. Regional airport system capacity coverage was defined as the cumulative number of airports within a certain distance of the closest significant airport serving a metropolitan region. Figure 76 illustrates the case of the regional airport system capacity coverage in the Boston region for which the closest airport to the center of Boston is Boston/Logan (BOS).

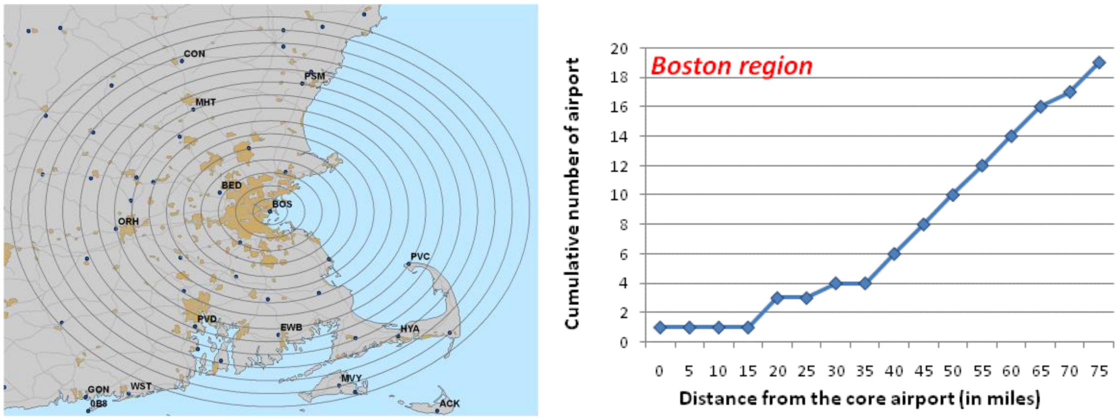

Figure 76: Regional airport system capacity coverage chart for the Boston region

As shown on Figure 76, there are 14 airports –with runways longer than 5,000 ft- around Boston/Logan (BOS) within 60 miles. Disregarding Boston/Logan (BOS), Boston/Manchester (MHT) and Boston/Providence (PVD), there are therefore 11 under-utilized airports in the metropolitan region (i.e. within 60 miles of Boston/Logan) that constitute a latent source of capacity.

- ***Presence of secondary basins of population***

While it is generally difficult to trace the exact origin or destination of passengers since no systematic data is recorded (i.e. the only sources of such data are surveys of passengers performed at airports), the presence of secondary basins of population within the metropolitan region can play a key role in the emergence of a secondary airport. In the absence of air service at the secondary airport, residents of these secondary basins of population have to travel to the remote primary airport or travel with other modes of transportation or not travel at all. With the emergence of service at a more closely located airport, these passengers now have improved access to air transportation. This factor is key in the demand stimulation mechanism previously illustrated (cf. Model, Figure 69, *demand to serve and to stimulate* loops).

- ***Congestion of primary airports***

A factor that is also key to the development and emergence of secondary airport is the congestion of the primary airport. As shown on Figure 69 (*i.e. Feedback model of the dynamics and factors influence the emergence of secondary airports*), that the airport utilization ratio (i.e. ratio of average flight demand divided by capacity)[1] is related to level of delays. Figure 77 shows the non-linear relationship between average percentage of delays and the airport utilization ratio[2] for OEP airports based on average data for the year 2000.

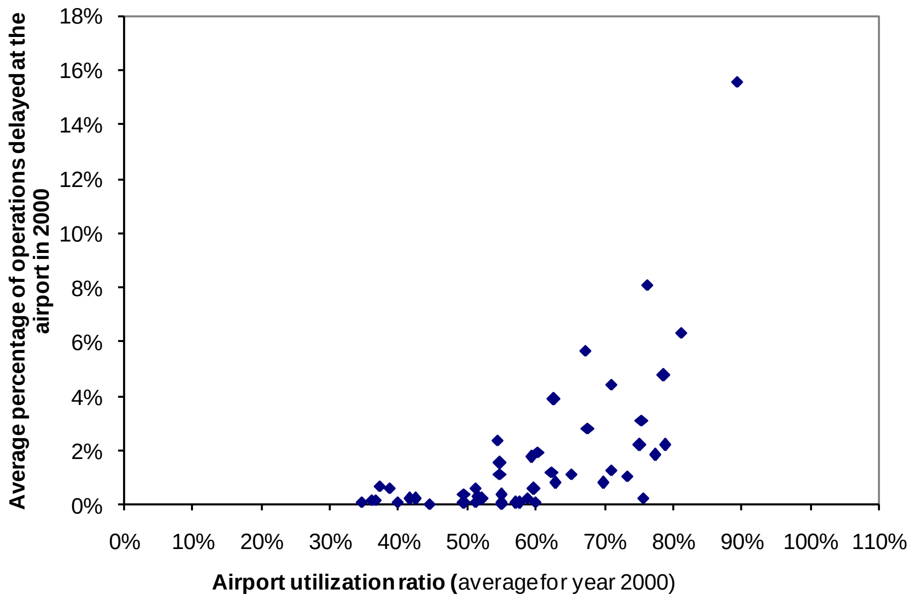

Figure 77: Relationship between delays and airport utilization ratio for major airports in the United States (i.e. OEP airports)

[1] Note: From principles of queuing theory, the airport utilization ratio (ρ) is computed as the ratio of the demand rate (λ) divided by the service rate (μ) of the airport system.
[2] Data source: Federal Aviation Administration (FAA) Airport Capacity Benchmark 2001.
Note: Computation of the utilization ratio based on a method of conversion of hourly capacity into annual capacity (de Neufville, et al., 2003)
Annual airport capacity was computed based on the following equation:
Annual Capacity $_{(\text{Airport } i)} = [(HR_{VFR\ i} \times f_{VFR\ i}) + (HR_{IFR\ i} \times f_{IFR\ i})] \times 24 \times 365 \times C_{day} \times C_{week}$
where HR_{VMC} is the Optimum Hourly Rate (in VMC conditions), HR_{IMC} the Reduced Hourly Rate (in IMC conditions), f_{VFR} the Fraction of the time in VMC conditions, f_{IFR} the Fraction of the time in IMC conditions, C_{day} the Correction factor for daily operations adjustment (i.e. set equal to 0.67), and C_{week} the Correction factor for weekly operations adjustment (i.e. set equal to 0.9).

Fundamentally, delays constitute externalities that users (i.e. airlines and passengers) have to internalize (Vickrey, 1969). From an airline management perspective, externalities are related to the costs incurred by the airlines and reduce the attractiveness of primary airports[1] (cf. Model, Figure 69, *Loss of attractiveness of primary airport to airlines* and *attractiveness of primary airport to passenger* loops). Since delays are lower at secondary airports, airlines and especially low-cost carriers that are seeking low-cost structures are more likely to enter and provide service at under-utilized airports.

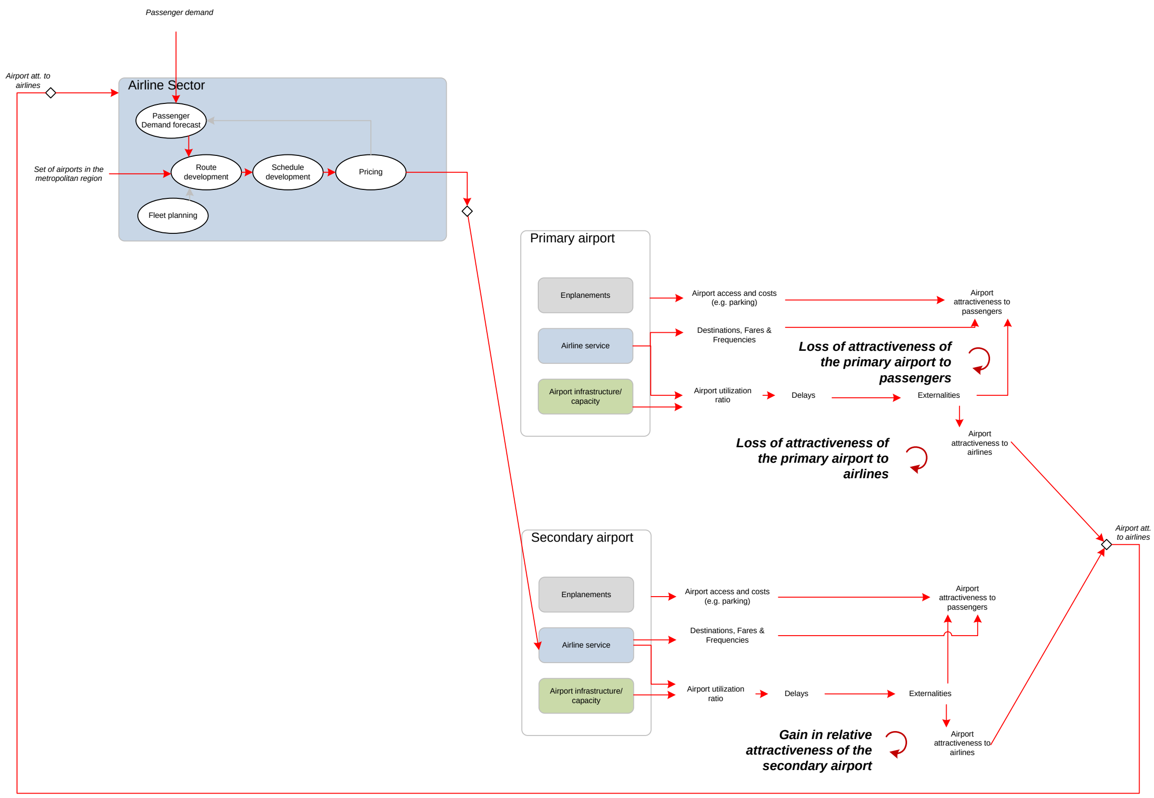

Figure 78: Role of congestion of primary airports in the feedback loop of entry of carriers at secondary airports

- ***Provision of airline entry incentives***

As shown on Figure 69, the emergence and growth of activity at secondary airports have positive impacts on the regional economic activity through direct, indirect and induced employment effects and through economic enabling effects (cf. Model, Figure

[1] Note: In some cases, negative delay externalities can be offset by economic benefits derived by airlines in the form of additional revenues in the case of connecting hub operations (cf. (Mayer, et al., 2003)).

69, *development driven by future positive regional economic impacts* loop). As a consequence, in return for potential and future regional economic benefits airport management authorities and local authorities that recognize these benefits can provide financial incentives to new entrant airlines.

- ***Role of ownership and management of airports***

For the same reasons that new carriers (e.g. low-cost carriers) enter service at an under-utilized airport based on projections of passenger demand and business potential, investment groups (i.e. institutional and private) can be motivated to acquire under-utilized airports for the projected airline and passenger traffic and cash flows that would generated in the long term. Figure 69 shows a simplified representation of the process and influence of investment groups on the acquisition and financing of airports.

8.2.2 Results from the multiple-case study analysis

c. *Sub-dynamics*

Entry of carriers (e.g. low-cost carriers)

As shown on Figure 69, the airline strategic planning processes (i.e. route development, schedule development, and pricing) influence the evolution of multi-airport systems through the emergence of secondary airports.

In order to assess the influence of the entry of carriers at secondary airports, an historical analysis of traffic patterns was performed. This analysis was based on passenger traffic data from ICAO[1] and FAA[2] and airport sources for the years 1976 to 2005. In addition, a large set of information and literature resources[3] were used to gather pieces of evidence to link changes in traffic patterns to the historical entry (or exit) of carriers at secondary airports.

Figure 79 illustrates the impact of the entry of Southwest airlines at Boston/Providence and Boston/Manchester in 1996 and 1998 respectively. The entry of a low-cost carrier is generally associated with significant increases passenger traffic.

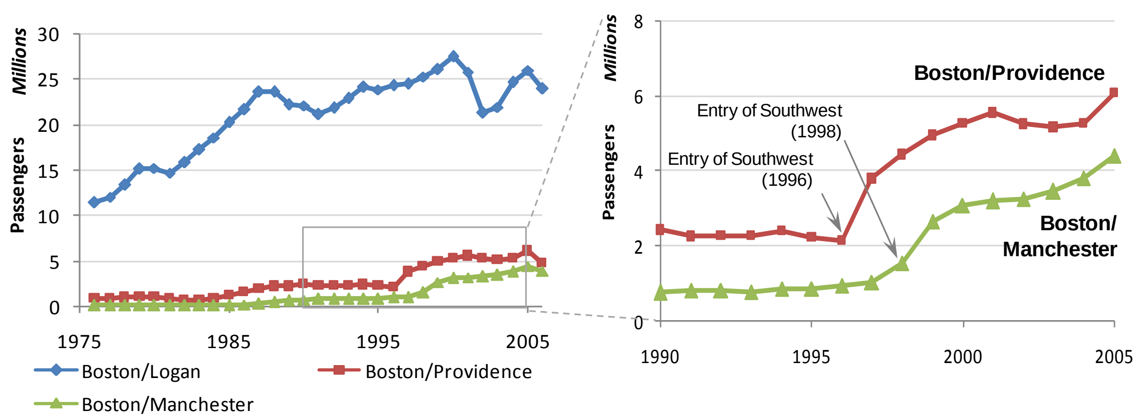

Figure 79: Impact of the entry of Southwest Airlines on passenger traffic at secondary airports in the Boston metropolitan region[4]

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[1] Data source: International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008.
[2] Data source: Federal Aviation Administration, "Terminal Area Forecasts", (historical records), available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: 2007.
[3] Data sources included: airline websites, airport websites, and industry news publications (cf. Appendix C).
[4] Data source: FAA Terminal Area Forecast, available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: February 2007.

In the case of Boston/Manchester and Boston/Providence, the impact of Southwest was substantial. At Boston/Manchester, the year-to-year growth in passenger enplanements averaged 6% from 1990 to 1997. After the entry of Southwest in 1998, it increased to 45% per year from 1998 to 2000. The same phenomenon occurred in the case of Boston/Providence where the year-to-year growth of passenger enplanements jumped from stagnation (from 1990 to 1996) to an average of 35% during the three years following the entry of Southwest.

The observation of this phenomenon is not limited to the United States. Figure 80 shows the case of the Frankfurt multi-airport system where Ryanair started to offer service at Frankfurt/Hahn in 1999. The airport had no scheduled service until the entry of Ryanair and exhibited annual growth rate of traffic ranging from 10% to 20% between the years 2003 to 2006. Frankfurt/Hahn handled 3,704,000 passengers in 2006.

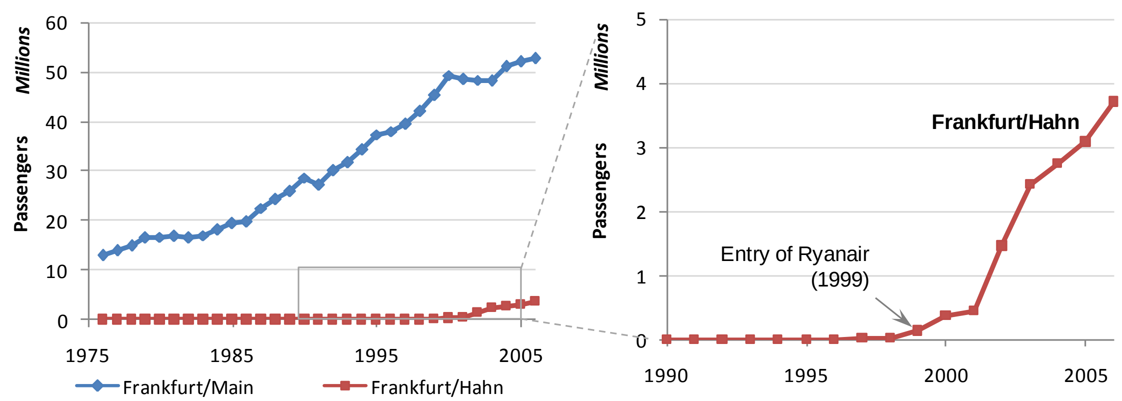

Figure 80: Impact of the entry of Ryanair on passenger traffic at Frankfurt/Hahn[1]

The analysis of the entry of low-cost carriers was performed for the set of 59 multi-airport systems. Table 11 summarizes the entries of low-cost carriers that stimulated the emergence and growth of secondary airports. Some of these airports also became primary airports. In the vast majority of the cases, Southwest Airlines in the United States and Ryanair in Europe were responsible for the emergence and growth of secondary airports. As shown Table 11, Southwest Airlines influence on the emergence of secondary airport can be traced back to its origin in 1971. Southwest started operating at Dallas/Love Field

[1] Data source: International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008.

(DAL). One year later, Houston/Hobby (HOU) grew again after its operations were moved to Houston/Intercontinental (IAH) in 1969.

Table 11: Entry of carriers that stimulated the emergence and growth of airports

World Region	Airport name	Low-cost carriers that influenced the emergence and growth of passenger traffic at secondary airports
Asia/Pacific	Bangkok/Don Mueang	One-Two-Go (2007)
	Melbourne/Avalon	Jetstar (2004)
Europe	Glasgow/Edinburgh	Ryanair
	Stuttgart/Karlsruhe Baden Baden	Ryanair (2003)
	Paris/Beauvais	Ryanair (1997)
	Milan/Bergamo Orio Al Serio	Ryanair (2004)
	Manchester/Blackpool	Jet2.com (base in 2005) - Ryanair
	Vienna/Bratislava	SkyEurope (2002)
	Brussels/South Charleroi	Ryanair (1988)
	Rome/Ciampino	Ryanair (2004)
	Amsterdam/Eindhoven	Ryanair
	Bologna/Forli	Ryanair (2002)
	Barcelona/Gerona	Ryanair (2004)
	Glasgow/Prestwick	Ryanair (1994)
	Gothenburg/City	Ryanair (2001)
	Frankfurt/Hahn	Ryanair (2002)
	Manchester/Leeds Bradford	Jet2.com (2003)
	Manchester/Liverpool	Ryanair (1987-base in 2005)
	Hamburg/Lubeck	Ryanair (2005) - Wizzair (2006)
	Copenhagen/Malmo	Ryanair (1998-2007) - Sterling Airlines
	Oslo/Sandefjord	Ryanair (1997)
	Barcelona/Reus	Ryanair (2004)
	Stockholm/Skavsta	Ryanair (1997)
	Venice/Treviso	Ryanair (1998)
	Dusseldorf/Weeze Niederrhein	Ryanair (2003)
Latin America	Mexico City/Toluca	Interjet (2005) - Volaris (2005)
Middle East	Dubai/Sharjah	Air Arabia (2003)
North America	Washington/Baltimore	Southwest (1993)
	Miami/Fort Lauderdale	Southwest (1996)
	New York/Newark	People Express (1980)
	San Francisco/Oakland	Southwest (1989)
	Vancouver/Abbotsford	Westjet (1997)
	Los Angeles/Burbank	Southwest (1990)
	Chicago/Midway	Midway (1979) - Southwest (1985)
	Dallas/Love Field	Southwest (1971)
	Houston/Hobby	Southwest (1972)
	New York/Islip	Southwest (1999)
	Los Angeles/Long Beach	Southwest (2002)
	Boston/Manchester	Southwest (1998)
	Los Angeles/Ontario	Southwest (1995)
	Los Angeles/Santa Ana	Southwest (1994)
	Boston/Providence	Southwest (1996)
	San Francisco/San Jose	Southwest
	Toronto/Hamilton	Westjet (2000) - Globespan (2007)
	Cleveland/Akron-Canton	AirTran (2004)
	Philadelphia/Atlantic City	Spirit Airlines
	Detroit/Bishop	AirTran
	San Diego/Tijuana	Avolar (2005)

The development of secondary airports in Europe is more recent. It was amplified after the deregulation of the European air transportation markets (1993-1997) that resulted in the development and growth of several low-cost carriers. Carriers such as Ryanair, SkyEurope and Wizzair opened new routes to and from secondary airports, following the business model established by Southwest Airlines.

Not all low-cost carriers exhibit the same service entry strategies and patterns of use of primary and secondary airports. Table 14 shows the distribution of operations between primary and secondary airports[1] from Oct. 2004 to Sept. 2005 for the top 30 low-cost carriers. These top 30 carriers were defined in terms of total number of operations performed across the set of primary and secondary airports. Some low-cost carriers tend to design their network primarily around secondary airports (e.g. Southwest airlines, Ryanair, SkyEurope, etc.). Others have hybrid approaches or even design their network solely around primary airports (JetBlue, WestJet, Transavia, etc.). This distinction is important since not all low-cost carriers are responsible for the emergence of secondary airports and that once the presence of low-cost carriers increase at the primary airports - even though their cost structure may be higher than low-cost carriers operating at secondary airports-, a different competition dynamic arise within airports in the metropolitan region.

[1] Note: The set of primary and secondary airports used for this analysis is the set of all primary and secondary airports part of the 59 multi-airport systems. The set of primary airports does not include airports outside multi-airport systems (i.e. single-airport systems) at which these carriers may also be operating.

Table 12: Distribution of traffic (flight departures and arrivals) between primary and secondary airports for the top 30 low-cost carriers[1]

Airline name	Percent Operations at Primary Airports	Percent Operations at Secondary Airports
Ryanair	5%	95%
SkyEurope	30%	70%
ATA Airlines	38%	62%
Southwest Airlines	47%	53%
Transavia Airlines	59%	41%
easyJet Airline	61%	39%
Jet2.com	68%	32%
Frontier Airlines	75%	25%
America West Airlines	75%	25%
Air Berlin	83%	17%
jetBlue Airways	87%	13%
WestJet	89%	11%
Flybe British	89%	11%
Norwegian Air Shuttle	90%	10%
germanwings	92%	8%
AirTran Airways	92%	8%
dba	93%	7%
Independence Air	95%	5%
Spirit Airlines	95%	5%
bmibaby	96%	4%
Virgin Express	98%	2%
Meridiana	99%	1%
Gol Transportes Aereos	100%	0%
Virgin Blue	100%	0%
Maersk Air	100%	0%
Lion Airlines	100%	0%
Bangkok Airways	100%	0%
AVIACSA	100%	0%
Transasia	100%	0%
Flynordic	100%	0%

Given the wide range of strategies and business models used by low-cost carriers, secondary airports tend to exhibit higher share of traffic by low-cost carriers. Table 13 shows the percentage of operations (i.e. flights) performed by low-cost carriers at primary and secondary airports.

[1] Data source: The Official Airline Guide (OAG), data from Oct 1st 2004 to Sept 30th 2005, traffic measured in number departures and arrivals.

Table 13: Share of traffic (measured in flight departures and arrivals) of low-cost carriers versus other airlines at primary and secondary airports worldwide[1]

World region	Percentage of Low-Cost Carriers	
	Primary airports	Secondary airports
Asia-Pacific	9%	100%
Europe	14%	68%
Latin America	17%	2%
Middle East	1%	7%
North America	17%	63%

a. Observed dynamics of entry of a new carrier (e.g. low-cost carriers) at secondary airports

In order to evaluate the causal relationship and the hypotheses of the impact of the entry of low-cost carriers at secondary airports on air carrier and airport attributes (i.e. traffic, fares, competition, etc.), historical analyses of evolution of fares, traffic and number of entries following the initial entry of a carrier were performed.

In the case of airports that were already served by carriers with very limited service and high fares, the entry of low-cost carriers resulted in a decrease of average fares. This stimulated the emergence process.

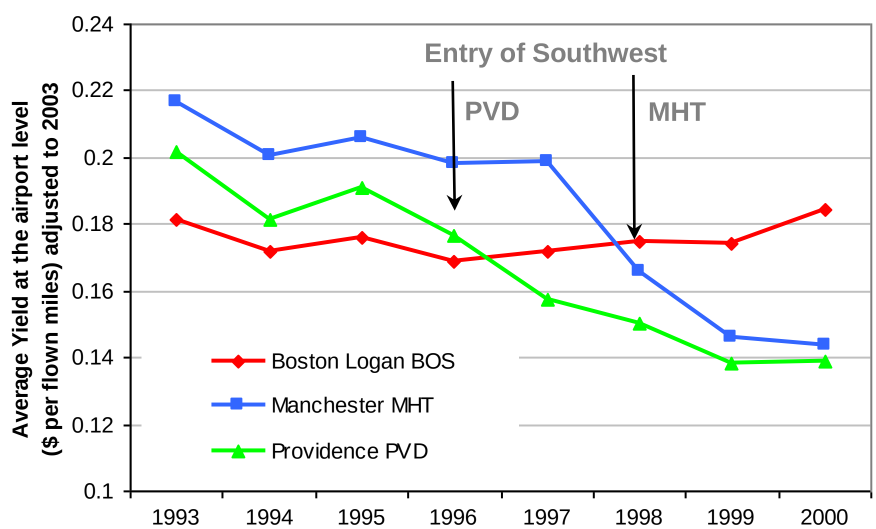

Figure 81: Evolution of average yield for Boston/Logan (BOS), Boston/Manchester (MHT), and Boston/Providence (PVD)[2]

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[1] Data source: The Official Airline Guide (OAG), data from Oct 1st 2004 to Sept 30th 2005, traffic measured in number departures and arrivals.

[2] Data source: Traffic data from Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: February 2007. Fare

In the case of Boston/Manchester (MHT), where Southwest Airlines entered service in 1998, the average aggregate yield at the airport level dropped by 27% (Figure 81) between 1997 and 1999, while the enplanements increased by 154%.

Figure 82 shows the stimulation of traffic resulting from the new services (i.e. new destinations and frequencies) at lower fares than in the past. When the average yield at the airport decreased at Boston/Manchester and Boston/Providence, traffic increased substantially. Similar dynamics were observed at other secondary airports. At Miami/Fort Lauderdale, the entry of Southwest resulted in a 22% decrease in average yield while traffic increased by 32%.

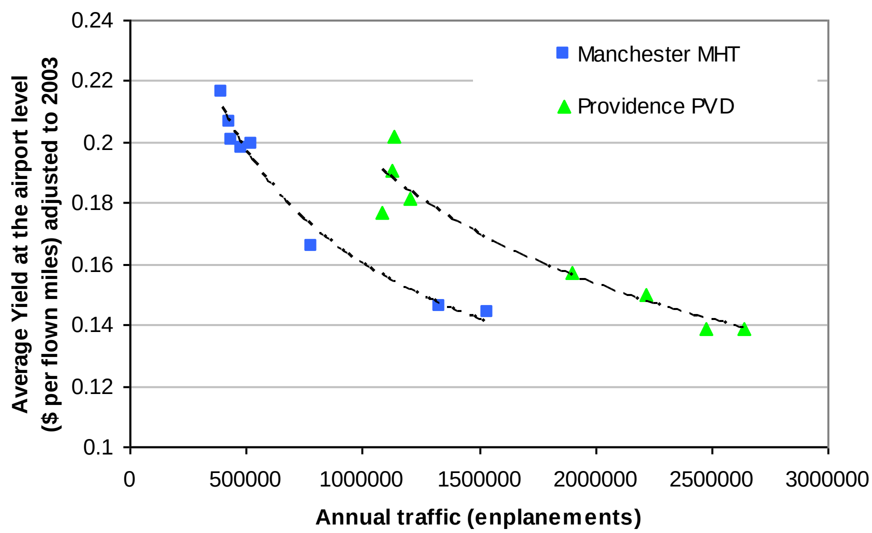

Figure 82: Yield versus passenger traffic at Boston/Manchester (MHT) and Boston/Providence (PVD)[1] from 1993 to 2000

Due to the limited availability of data on fares prior to 1994, it was difficult to capture changes in airport dynamics resulting from the entry of a low-cost carrier prior to 1994. However, the results of the analysis on the change in airport dynamics after the entry of a low-cost carrier is consistent with a study performed in 1993 by the FAA

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database from; Research and Innovative Technology Administration (RITA) U.S. Department of Transportation's (DOT), Bureau of Transportation Statistics (BTS), Origin and Destination Survey: DB1BMarket, available at: http://www.transtats.bts.gov/, Washington, DC, last accessed; February 2007.

[1] Data source: Traffic data from Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: February 2007. Fare database from; Research and Innovative Technology Administration (RITA) U.S. Department of Transportation's (DOT), Bureau of Transportation Statistics (BTS), Origin and Destination Survey: DB1BMarket, http://www.transtats.bts.gov/, Washington, DC, last accessed; February 2007.

Office of Aviation (Bennett, et al., 1993) that focused on the impact of Southwest entry, also known as the "Southwest effect", on the routes between airports in Los Angeles and San Francisco multi-airport systems. However, this effect was only studied and demonstrated at the route level between airports that are part of the Los Angeles and San Francisco multi-airport systems. In the case of Boston/Manchester, Boston/Providence and Miami/Fort Lauderdale the impact of the entry of a low-cost carrier is clearly observed at the airport level.

The entry of a specific carrier and the drop of fares were not the only changes in the dynamics of the secondary airport. Following the entry of the new, generally low-cost, carrier several other carriers entered and offered service at the secondary airport. These entries changed the dynamic at the airport level. Figure 83 shows the number of departures per day at Boston/Manchester, Boston/Providence, New York/Islip, Miami/Fort Lauderdale and Chicago/Midway from 1996 to 2003[1]. In the case of Boston/Manchester, it was found that following the entry of Southwest in 1998, several other carriers, such as Northwest, Continental, Delta and ACA, started service at this airport. These subsequent entries increased the level of competition at this airport. Similar phenomena are observed at other secondary airports as shown in Figure 83.

[1] Due to limited availability of traffic data, only recently emerged secondary airports such as Boston/Manchester, Boston/Providence, New York/Islip, Miami/Fort Lauderdale and Chicago/Midway have been analyzed. The literature review also covered cases of secondary airports that emerged prior to the 1990s.

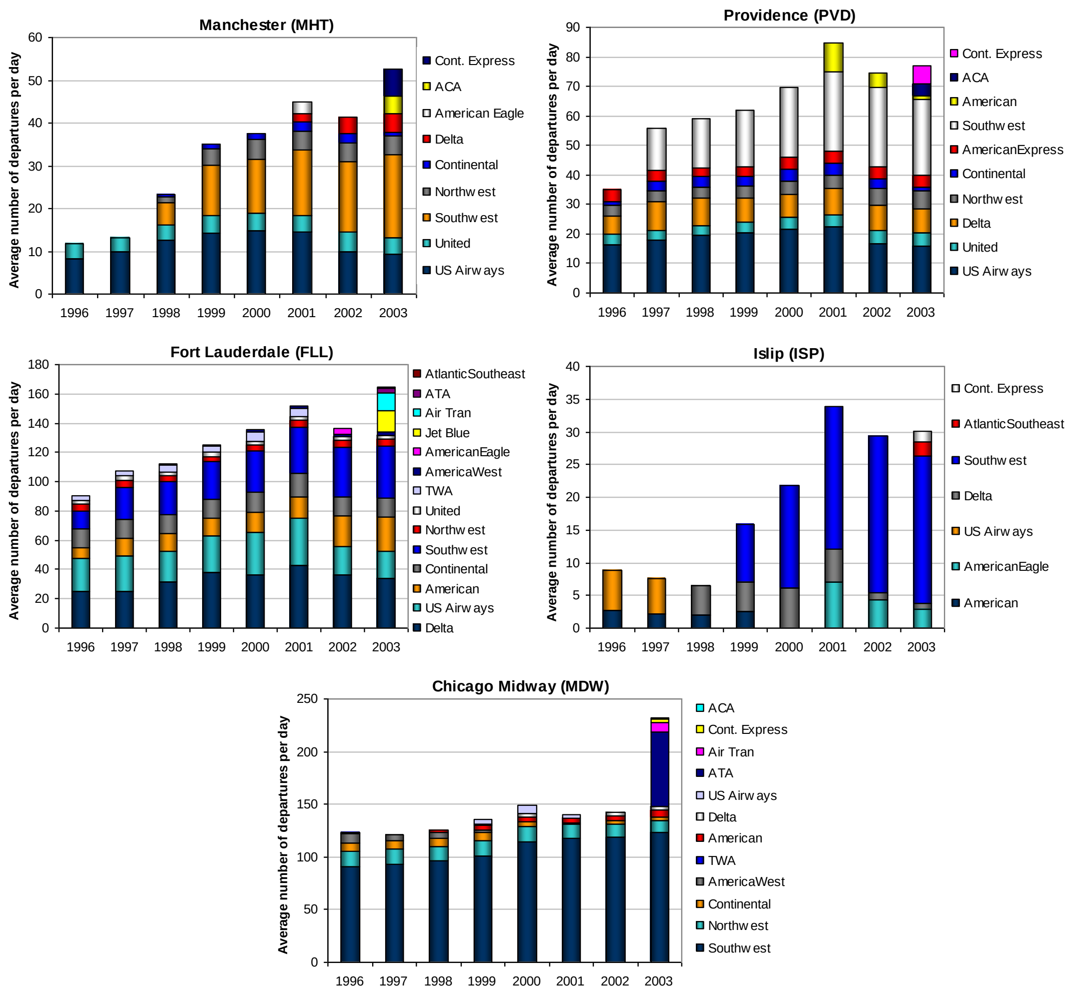

Figure 83: Illustration of historical evolution of traffic share[1] of airlines operating at a sample of secondary airports in the United States from 1996 to 2003

For airports outside the United States, detailed historical traffic data by airline was not accessible. A historical analysis of subsequent carriers' entries was performed using available information from airport and airline websites, and industry news sources. Table 14 shows the non-exhaustive list of carriers that followed the entry of a leading low-cost carrier at secondary airports.

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[1] Data source: DOT Bureau of Transportation Statistics (BTS), Air Carrier Statistics (Form 41 Traffic)- All Carriers, T-100 Domestic and International Markets, available at: http://www.transtats.bts.gov/, last accessed; December 2007 and Historical records from Federal Aviation Administration, "Terminal Area Forecasts", available at http://www.apo.data.faa.gov/faatafall.htm, Last accessed: February 2007.

Table 14: Illustrations of subsequent entries of carriers following the entry of a low-cost carrier

Airport name	Subsequent entry of low-cost carriers (and legacy airlines)
Vancouver/Abbotsford	BCWest Air
Stuttgart/Karlsruhe Baden Baden	Air Berlin, Air Via, Freebird Airlines, Hamburg International, Sky Airlines, SunExpress and TUIfly
Paris/Beauvais	Wizzair, Blue Air, Centralwings, blueislands
Milan/Bergamo Orio Al Serio	Wizz Air, MyAir
Manchester/Blackpool	Ryanair, Monarch Airlines
Brussels/South Charleroi	Wizzair, OnAir, Jet4You.com
Rome/Ciampino	Centralwings, EasyJet, and Wizz Air
Dusseldorf/Dortmund	Easy Jet in 2004 and Germanwings in 2007
Amsterdam/Eindhoven	Transavia.com, KLM Cityhopper, Denim Airways, Airlinair, Iceland Express, Corendon Airlines
Bologna/Forli	Wind Jet, South Airlines, Ryanair, Ukraine International, Belle Air, Cimber Air
Miami/Fort Lauderdale	Spirit (1999), JetBlue (2001), Air Tran
Barcelona/Gerona	Wizz Air, Centralwings, Thomsonfly, Transavia.com
Gothenburg/City	WiaaAir, Air Berlin
Frankfurt/Hahn	Wizz Air, Iceland Express
Dusseldorf/Cologne Bonn	easyJet in 2003 and Wizzair in 2006
London/Luton	easyJet
Hamburg/Lubeck	Wizz Air, Jet2.com
Copenhagen/Malmo	Sterling Airlines
Boston/Manchester	American, ACA, Continental Express, Northwest Airlines
Oslo/Sandefjord	Wizz Air
Boston/Providence	Northwest, Continental, Delta, American Eagle, Air Canada
Barcelona/Reus	Astraeus, British Midland Airways, First Choice Airways Futura Intenacional, Iberia Iberworld, Jetair Fly, LTE International Airways, Monarch Airlines My Travel Airways, Swiss International Air Lines, Thomsonfly
Amsterdam/Rotterdam	Fly VLM
Tampa/St Petersburg	Allegiant
Stockholm/Skavsta	Wizzair
Toronto/Hamilton	Flyglobespan
Dusseldorf/Weeze Niederrhein	Sky Airlines, Hamburg International

The number of air carriers generally increased following the entry of a specific carrier. This increased level of competition at the secondary airport was also a significant factor in the success of its emergence. As a result, an in depth analysis of the change in airport competitive environment was performed. In order to measure the change in competition levels, Herfindahl-Hirschman Indexes (HHI) were computed. HHI is a measure of the size of firms in relationship to the industry and indicates the competition level among them. HHI is defined as the sum of the squares of the market shares (MS) of each individual firm. It can thus range from 0 to 10,000, moving from a very large amount of very small firms to a single monopolistic firm. Decreases in the Herfindahl-Hirschman index generally indicate a loss of pricing power and an increase in competition, whereas increases imply the opposite. Taking the market as the airport and airlines as the firms, the HHI were computed as based on Form 41 annual number of departures in 1991 and 2000.

Equation 10:

$$HHI_i = \sum_{\substack{airlines\_at \\ airport\_i}} MS^2$$

Table 15: Illustration of evolution of market concentration at the airport level for four multi-airport systems in the United States

Airport	Herfindahl-Hirschman Index in 1991	in 2000	Variation
LGA	1200	1300	8%
ISP	3600	2900	**-19%**
BOS	1300	1200	-8%
PVD	2300	1700	**-26%**
MHT	3000	1800	**-40%**
MIA	2000	2400	20%
FLL	1700	1100	**-35%**
ORD	2900	2600	-10%
MDW	5100	2800	**-45%**

Table 15 shows the HHI values for five secondary airports for 1991 and 2000. In addition, HHIs were computed at primary airports in order to have a reference within each regional airport system. Table 15 also shows the variation of the competition level between 1991 and 2000.

It was found that the market concentration significantly decreased at secondary airports over the time period of study. The decrease in HHI at secondary airports ranged from 19% at New York/Islip to 45% at Chicago/Midway. HHIs at the reference airport – the primary airport- did not decrease as much (the largest decrease was observed at Chicago/O'Hare with 10% compared to the 45% decrease at Chicago/Midway) and even increased in the case of New York/LaGuardia and Miami/Intl (+20% for Miami/Intl). The sharper decrease in HHI at secondary airport due to the entry of a low-cost carrier and several followers (Table 15) implies that airlines that were operating at secondary airports lost monopolistic and pricing power. It is believed that this loss of pricing power combined with the presence of low-cost carriers offering low fares, in addition to more destinations and frequency play a fundamental role in the successful emergence of the secondary airports and their sustainable growth.

d. Factors influencing the emergence of secondary airports

The entry of a low-cost carrier which triggered the emergence of a secondary airport was the result of a business decision by a single air carrier. However, this decision was based on factors such as market potential (demographics, economics, etc.), airport capabilities (infrastructure capabilities, etc.), easiness to compete for traffic with the primary airport, etc.

- ***Availability of airport infrastructure in the metropolitan region***

As shown in Figure 62, the availability of airport infrastructure (i.e. under-utilized airports) in the region was assessed as a key factor influencing the dynamics of emergence of secondary airports and the construction of new airports.

Generally, new airports in the metropolitan region are generally located further away from the city center than the existing primary. Figure 84 shows the results of an analysis of the geographical location of airports in metropolitan regions (i.e. distribution of distance between the center of the city and airports). It shows that original primary airports are generally located within 20 miles of the city center (with closed primaries located within the first 15 miles). Then primary airports that were newly constructed are generally located further away than original primary airports (10 to 30+ miles from the city center) and emerged secondary airports generally located in the 20 to 60 miles ring around city center.

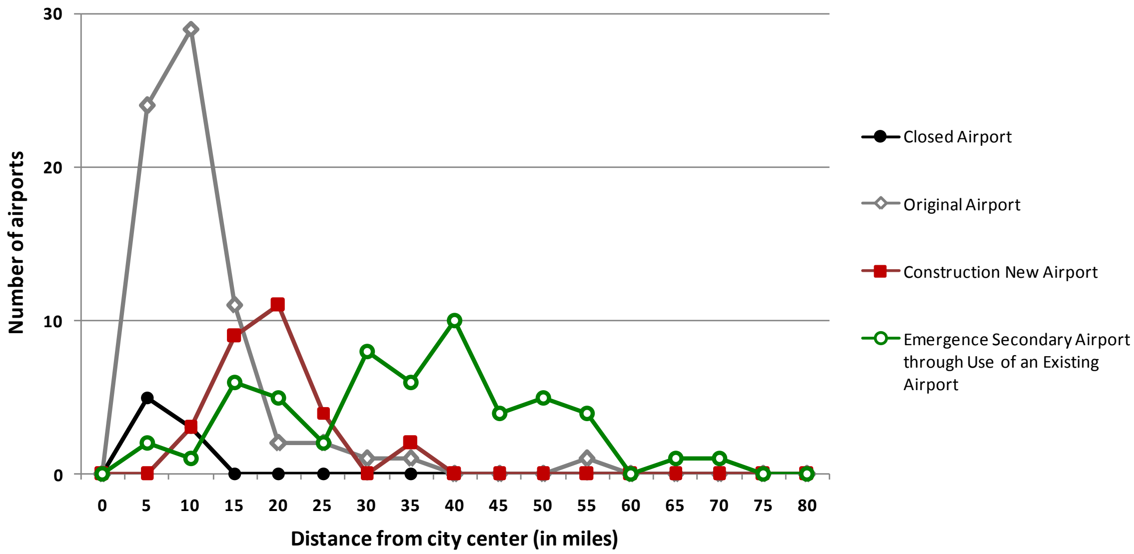

Figure 84: Number of airports (by type) as a function of distance from the center of the city

In order to evaluate the availability of airport infrastructure in the metropolitan region and its influence on the dynamics of emergence of secondary airports and the construction of new airports, an analysis of the regional airport system capacity coverage was performed. Regional airport system capacity coverage charts were constructed for each of the 59 airport systems. This analysis was performed using a worldwide airport database (DAFIF, 2005) of all airports with at least one runway longer than 5000 ft. To contrast the availability of airports across different world regions, the results were averaged by world regions. Figure 85 shows the cumulative number of existing airports by distance from the airport closest to the center of the city.

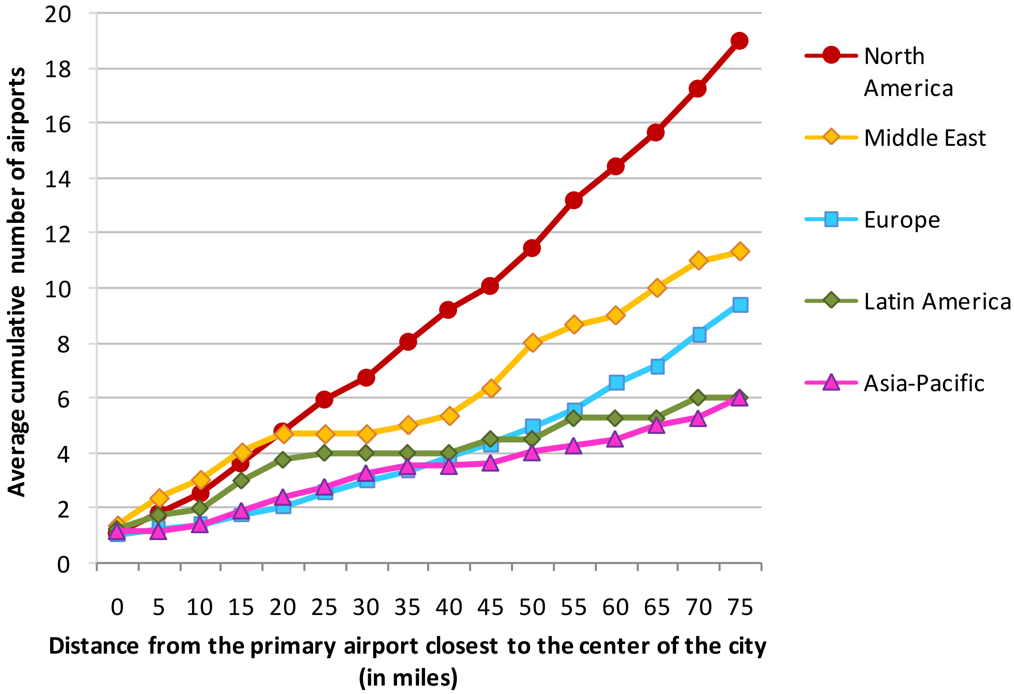

Figure 85: Regional airport system capacity coverage: cumulative number of airports (civil and military airports with at least one runway longer than 5000 ft) by distance from the central primary airport[1]

In order to truly assess the availability of existing under-utilized airports, the 144 airports identified in the analysis of multi-airport systems were excluded from the regional airport systems capacity coverage presented in (Figure 85). Figure 86 shows the regional airport systems capacity coverage of civil and jointly operated airports (DAFIF Category A & B airports) with at least one runway longer than 5000 ft (Figure 86) excluding the primary and secondary airports that have already emerged.

[1] Data source: (DAFIF, 2005)

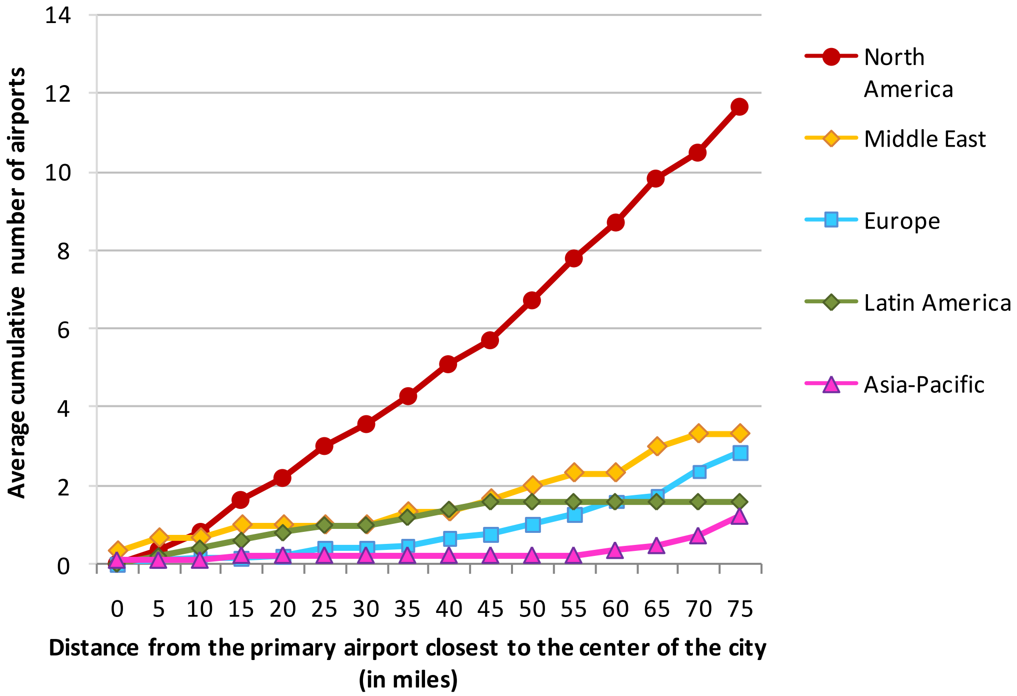

Figure 86: Regional airport system capacity coverage: cumulative number of existing airports (civil airports with at least one runway longer than 5000 ft) by distance from the central primary airport[1]

As shown on Figure 86, North America is characterized by a high density of existing airports. This explains that in the presence of barriers to the construction of new airports, this set of available airports has been utilized and resulted in the emergence of secondary airports. Conversely, the low density or absence of existing airports in Asia-Pacific and South America is a factor responsible for the observed predominant trend of construction of airports (cf. Chapter 7).

[1] Data source: (DAFIF, 2005)

- ***Changes of airport status; conversion from military to civil status***

While the density of available civil or joint-use airports in Europe is low (Figure 86), the reason for the predominant dynamic of emergence of secondary airports is partially explained by the conversion of military airports into civil or joint-use airports. The analysis of the historical evolution of the status of airports[1] (i.e. civil, joint-use, military) showed that, in Europe, 13 airports that emerged as secondary airports were previously military airfields. Table 16 shows the number of military airports converted into secondary airports across different world regions. In North America, four airports have been converted. In the Asia-Pacific region, the only secondary airport that emerged was converted from a military airfield (i.e. Melbourne/Avalon).

[1] Note: Because a very large number of airports worldwide were used for military purposes during World War II, only airports that were still used for military purposes and converted after 1955 were considered and are presented in this analysis.

Table 16: Cases of former military airports that emerged as secondary airports

World Region	Airport name	Brief description of the history and airport conversion process
Europe	Paris/Beauvais	Beauvais was used as a military base during WWII and opened to civil use in 1956.
	Dusseldorf/Cologne Bonn	Developped in 1939 as a military airfield for the German Luftwaffe. Used by the British military after WWII that expanded the airport. In 1951 the airport was opened for civilian air traffic.
	Dusseldorf/Weeze Niederrhein	Weeze airport was originally a Royal Air Force base (i.e. RAF Laarbruch) and was the base of several squadrons. After closing in 1999 the airfield was transformed into a civil airfield. Civil operations began in May 2003 with the entry of Ryanair.
	Frankfurt/Hahn	Frankfurt Hahn was built in 1947 as a NATO military base (Hahn Air Base; home of the United States Air Force 50th Fighter Wing). In 1993, most of Hahn Air Base was transferred to civil German authorities that transformed the airport into a civil airport.
	Stuttgart/Karlsruhe Baden Baden	Baden Airpark was a Canadian military base and airport (CFB Baden-Soellingen) from 1953 until 1993. It was transferred to civil use in 1993 and opened in 1997.
	Milan/Bergamo Orio Al Serio	Bergamo - Orio al Serio was constructed in 1937 as a military base and opened for civilian traffic in 1972.
	Venice/Treviso	Venice Treviso was military air base (i.e. 2nd Squadron) with Fiat G-91.
	Barcelona/Reus	Reus airport was used as military facility until 1998. Since 1998, Reus Airport has served civil aviation exclusively.
	Gothenburg/City	Gothenburg City was originally built as a military airbase in 1940 (i.e. Saeve AB) which closed in 1969.
	Stockholm/Skavsta	Stockholm Skavsta (NYO) airport was established as a military air base in the 1940s and developed into a civilian airport in 1984.
	Glasgow/Prestwick	Glasgow Prestwick was used as a US Air Force based from 1952 until 1966.
	London/Stansted	Stansted was built in 1942 and use as a military base during World War II. It opened to civil use in 1969.
	Hamburg/Lubeck	Hamburg/Lubeck is a former Royal Air Force (RAF) base (i.e. RAF Blankensee)
North America	Toronto/Hamilton	During World War II, Toronto Hamilton was used of as an Air Training facility. After the war, it was gradually transferred to civil use. In 1963, the Canadian Department of National Defense declared the intention of decommissioning the airport and transferred its ownership and control to the Department of Transportation. Military use stopped in 1964. The City of Hamilton assumed responsibility for the maintenance and operation of the airport in 1967.
	Vancouver/Abbotsford	Abbotsford was used as a British Commonwealth Air Training Plan airport (i.e. No. 24 Elementary Flying Training School). In 1958, the airport was officially transferred to the Department of Transport. In 1997, following the national trend of transfer of ownership of airports to public or private airport authorities, the Canadian Department of Transport transferred ownership of Abbotsford to the City of Abbotsford.
	Orlando/Sanford	Orlando Sanford was used as military base during WWII and then returned to civil use temporarily. After the Korean War began in 1951, the Navy once again acquired the airport. The airport operated as a training base for fighter, attack, and reconnaissance aircraft until it closed in June of 1968 and the City of Sanford reacquired the airport and took the operational control. In 1971, the Sanford Airport Authority was created and became responsible for the operation, maintenance, and development of the airport.
	Philadelphia/Atlantic City	The Naval Air Station (NAS) Atlantic City was decommissioned in 1958.
Asia/Pacific	Melbourne/Avalon	Avalon was built in 1953 as a military aircraft production facility and was used until the 1980s. The airport was later used as a maintenance facility until 1996. The Australian government converted the airport to civil use in 1997 and sold it to an infrastructure and transport investment company; Lindsay Fox.

- ***Presence of secondary basins of population in the vicinity of emerged airports***

As shown on Figure 69, the presence of secondary basins of population in the region can be a source of latent demand for a secondary airport and motivate the entry of carriers (e.g. low-cost carriers). In order to evaluate the influence of the presence of secondary basins of population within the 59 metropolitan regions in the case study analysis, a spatial analysis of the population distribution within the metropolitan region was performed. This analysis was based on ArcGIS® data[1] based on census information from year 2000. In addition, quantitative data of population of cities and metropolitan areas from a United Nation database[2] was used (Table 17 and Table 18).

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[1] Source: ESRI ArcGIS 9.x software and data from MIT Geodata Repository, available through MIT license, last accessed; January 2008.

[2] Data source: United Nations (UN), Demographic Yearbook, Table 8; Population of capital cities and cities of 100,000 and more inhabitants: latest available year, available at: http://unstats.un.org/unsd/demographic/sconcerns/densurb/densurb2.htm#City, last accessed; February 2008.

Table 17: Presence of secondary basins of population in the vicinity of emerged secondary airports

Airport name	Presence of secondary basins of population in the vicinity of the secondary airport
Amsterdam/Rotterdam	The airport is located close to the city of Rotterdam (i.e. population 584,046).
Bologna/Forli	Forli International Airport airport is located 2.2 miles from the city of Forli (population of 112,477).
Boston/Providence	T.F. Green Providence airport is located 7 miles from the center of Providence (RI). Providence represents a strong secondary basin of population in the Boston region. In 2004, the Providence urban area had a population of 1,174,548 (UN 2004).
Boston/Manchester	Manchester airport is located 4 miles from the city center of Manchester (NH). Similarly to Providence (RI), Manchester represents a secondary basin of population in the Boston region. In 2004, the Providence urban area had a population of 143,549 (UN 2004).
Cleveland/Akron-Canton	Cleveland/Akron-Canton is located 12 miles from the city of Akron (OH) which represents a secondary basin of population in the Cleveland metropolitan region. In 2000, the city of Akron had a population of 217,000 and 695,000 for its metro area.
Copenhagen/Malmo	Malmo airport is located 17 miles from the center of the city of Malmo (i.e. population; 280,000 for the city and 605,000 for the metropolitan area).
Detroit/Bishop	Detroit/Bishop is located 4 miles from the city of Flint which represents a secondary basin of population in the greater Detroit metropolitan region. In 2000, the city of Flint had a population of 125,000 and 444,000 for its metro area.
Dusseldorf/Dortmund	Located close to the city of Dortmund (i.e. population of 585,045 in 2008).
Hamburg/Lubeck	Lubeck airport is located 5 miles northwest of the city of Lubeck, which is a secondary basin of population in the greater Hamburg metropolitan region. Lubeck had a population of 213,983 in 2005. The city is located in the district of Schleswig-Holstein, located east of Hamburg and has a population of 2,837,021 in 2007).
Los Angeles/Santa Ana	Orange county airport is located 4 miles from the city center of Santa Ana (population: 337,977) and 7 miles from the center of Orange city (population: 128,821). Both cities are located Orange county which had 2,846,289 residents according to the 2000 US census.
Los Angeles/Ontario	Ontario airport is located in the San Bernardino-Riverside-Ontario area also known as the inland empire. In 2000, this MSA (Metropolitan Statistical Area) had 4,026,135 residents.
Los Angeles/Long Beach	Long Beach airport is located 3.9 miles from the city of Long Beach (population: 461,522) and 2.4 miles from the city center of Lakewood (population: 88,253) which are both located in Los Angeles county.
Los Angeles/Burbank	Burbank airport is 3 miles from the center of Burbank (CA) which represents a secondary basin of population in the Greater Los Angeles Area. In 2004, Burbank had a population of 100,316 (UN 2004). Burbank is in located in the same county as Los Angeles with a total population 9,948,081 residents in 2006 (US Census).
Manchester/Liverpool	Liverpool airport (i.e. similarly to the three secondary airports that serve the Manchester region) is also serving the secondary basin of population of the city of Liverpool (i.e. population of the city 436,100 in 2005)
Manchester/Leeds Bradford	Leeds Bradfrod airport (i.e. similarly to the three secondary airports that serve the Manchester region) is also serving the secondary basin of population of the city of Leeds (i.e. population of the city 443,247).
Manchester/Blackpool	Blackpool airport (i.e. similarly to the three secondary airports that serve the Manchester region) is also serving the secondary basin of population of the city of Blackpool (i.e. population of the city 142,700).

Table 18: Presence of secondary basins of population in the vicinity of emerged secondary airports (continued)

Airport name	Presence of secondary basins of population in the vicinity of the secondary airport
Melbourne/Avalon	Melbourne also serves the secondary basin of population of Geelong, located south of the airport, which had a population of 160,991 in 2006.
Mexico City/Toluca	Licenciado Adolfo López Mateos airport is located 6 miles northwest of the city of Toluca, which is a rapidly growing urban area and now the fifth largest in Mexico. In 2005, Toluca had 747,512 residents and its urban area had a population of 1,610,786 (UN, 2004).
Miami/Fort Lauderdale	Fort Lauderdale airport is located 3.4 miles from the center of Fort Lauderdale (FL) which represents a secondary basin of population in the Miami metropolitan region. In 2004, the Fort Lauderdale city had a population of 152,397 (UN 2004).
Milan/Bergamo Orio Al Serio	Orio al Serio International Airport airport is located 3 miles from the city of Bergamo in Lombardy, northeast of Milan. The city of Bergamo had a population of 117,072. This city is also located within the Province of Bergamo which had population of 1,022,428 in 2006.
New York/Islip	Islip (Long Island Mac Arthur) airport is located 7 miles from the city of Islip (population: 322,612 US Census 2000) which are both located in Suffolk county (population: 1,419,369 US Census 2000) which is covers most of Long Island.
Orlando/Sanford	Orlando Sanford is located close to the city of Sanford which is in the county of Seminole (i.e. population 365,196 in 2000).
Philadelphia/Atlantic City	Philadelphia/Atlantic City is located 9 miles from the center of Atlantic City (population of 41,000 and 271,000 for the metro area according to the 2000 Census). Atlantic City is also a tourist destination (e.g. casino and gambling industry).
San Diego/Tijuana	San Diego/Tijuana is located 3 miles from the city center of Tijuana. In 2005, the city of Tijuana had a population of 1,286,000 and 4,923,000 for its metro area.
San Francisco/San Jose	San Jose airport is located 2 miles from the center of San Jose (CA) which represents a secondary basin of population in the San Francisco metropolitan region. In 2004, San Jose had a population of 894,943 (UN 2004). In addition, San Jose is part of the Santa Clara County (e.g. primary site of Silicon Valley) which had a population of 1,682,585 in 2000 (US census).
San Francisco/Oakland	Oakland airport is located 6 miles from the center of Oakland (CA) which represents a secondary basin of population in the San Francisco metropolitan region. In 2004, Oakland had a population of 399,484 (UN 2004) and Alameda county which covers most of the East Bay region of the San Francisco Bay Area had a population of 1,443,741 in 2000 (US census).
Tampa/St Petersburg	Due to the presence of water areas that constrain the direct access between the three airports in the region, the secondary basins of population play a key role. In addition, the airports have significant leisure traffic. St Petersburg is located close to the city of Clearwater (i.e. population 108,687 in 2005), which is located in the Pinellas County (i.e. population 928,031).
Toronto/Hamilton	Toronto Hamilton airport is located 7 miles southwest of the city of Hamilton Ontario (population: 504,559 Statistics Canada 2006).
Vienna/Bratislava	Bratislava airport is located 5 miles from the city of Bratislava (population of 426,091), which the largest city in Slovakia.
Washington/Dulles	In 1962, when Washington Dulles opened the density of population around the airport was much lower than it is today. The development of the airport was also a source of economic development in the region.

- ***Congestion of primary airports***

As shown in Figure 62, the congestion of the primary airport can trigger the emergence of a secondary airport and the construction of new airports. In order to test the hypothesis of capacity constraints to explain traffic redistribution within the region, initial data of delays at airports, qualitative evidence of congestion and historical data of entries of carriers at secondary airports and construction of airports were collected.

Detailed quantitative data of airport delays was limited to the top airports in the United States (Table 19). Since delays are an indicator of airport capacity shortfall and constraints, an attempt to correlate the level of delays and the development of multi-airports in a region was performed.

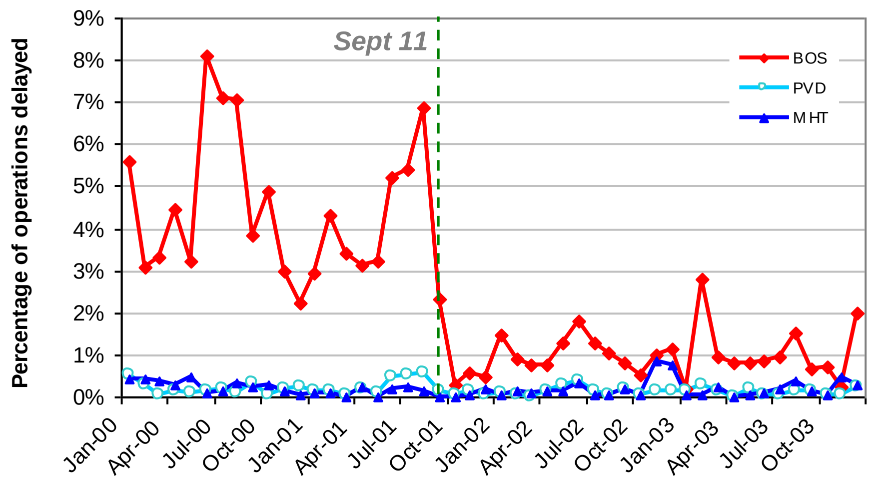
Table 19: Major airports in the United States ranked by decreasing percentage of delays and presence of secondary airports in the metropolitan region[1]

Airport code	Airport name	Percentage of arrivals delayed in 2005	Part of Multi-Airport System
EWR	New York/Newark	32.7	Yes
LGA	New York/LaGuardia	29.0	Yes (slot restricted)
JFK	New York/Kennedy	27.2	Yes (slot restricted)
ATL	Atlanta	25.7	
PHL	Philadelphia	25.7	Yes
BOS	Boston/Logan	25.2	Yes
MIA	Miami/Intl	24.7	Yes
SFO	San Francisco/Intl	23.5	Yes
IAD	Washington/Dulles	21.2	Yes
LAS	Las Vegas	21.1	
TPA	Tampa/Intl	20.9	Yes
SEA	Seattle	20.8	
MCO	Orlando/Intl	20.7	Yes
MEM	Memphis	20.5	
ORD	Chicago/O'Hare	20.4	Yes (slot restricted)
SAN	San Diego	20.0	Yes
BWI	Washington/Baltimore	19.6	Yes
LAX	Los Angeles/Intl	18.8	Yes
CLT	Charlotte	18.7	
PIT	Pittsburgh	18.3	
MSP	Minn./St. Paul	18.1	
DTW	Detroit	17.5	Yes
PHX	Phoenix	17.1	
DCA	Washington/Reagan	16.9	Yes (slot restricted)
IAH	Houston/Intercontinental	16.9	Yes
SLC	Salt Lake City	16.5	
CVG	Cincinnati	16.1	
DFW	Dallas/Fort Worth	16.1	Yes
DEN	Denver/Intl	15.8	
STL	St Louis/Lambert	15.8	

[1] Data source: US Federal Aviation Administration (FAA), Aviation System Performance Metrics (ASPM), Airline Service Quality Performance (ASQP), available at: http://aspm.faa.gov/aspm/entryASPM.asp, last accessed; April 2008.

Table 19 shows that primary airports within multi-airport systems tend to exhibit high level of delays. Inadequate airport capacity generates externalities and degrades level of service and results in a decreased attractiveness of the primary airport to both airlines and passengers. This increases the attractiveness of closely located and under-utilized airports that do not exhibit the same congestion problems. This difference in airport attractiveness provides an incentive for carriers to enter and use under-utilized airports within the metropolitan region.

In order to evaluate the difference in level of delays between the primary and secondary airports, a historical analysis of delays was performed. Using FAA delay data[1], the study covered the period from 2000 to 2003. Figure 87 and Figure 88 show the percentage of operations delayed at both primary and secondary airports within the metropolitan regions of Boston and New York.



Data source: US Federal Aviation Administration (FAA) OPSNET data.
Note: By the nature of the definitions of delays and reporting process, OPNSET data underestimates the true extent of delays. The use of this data in this figure is for airport to airport delay comparison purposes.

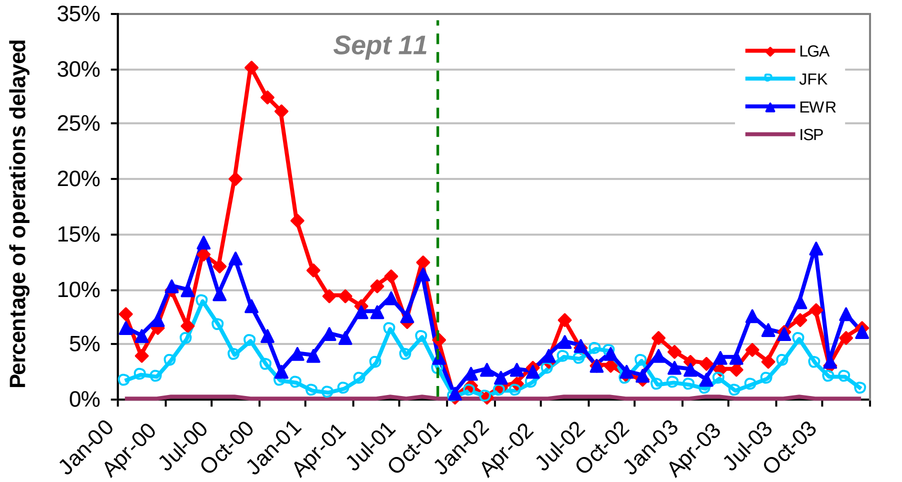
Figure 87: Percentage of operations delayed at Boston/Logan (BOS), Boston/Manchester (MHT), and Boston/Providence (PVD)[2] from 2000 to 2003

[1] Data source: US Federal Aviation Administration (FAA) OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: April 2008. Note: Due to the unavailability of delay data reported through the Airline Service Quality Performance (ASQP) database for secondary airports, OPSNET data was used for the comparative analysis. OPSNET data underestimates the true extent of delays but it sufficient for the purpose of this comparative analysis.

[2] Data source: US Federal Aviation Administration (FAA) OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: April 2008.

As shown on Figure 87, Boston/Manchester (MHT) and Boston/Providence (PVD) airports exhibit significantly lower levels of delays than Boston/Logan (BOS), even a few years after the entry of Southwest Airlines[1].

Similarly, New York/Islip airport (ISP), in the New York multi-airport system, exhibits lower levels of delay compared to the primary airports in this system.



Data source: US Federal Aviation Administration (FAA) OPSNET data.
Note: By the nature of the definitions of delays and reporting process, OPNSET data underestimates the true extent of delays. The use of this data in this figure is for airport to airport delay comparison purposes.

Figure 88: Percentage of operations delayed at New York/LaGuardia (LGA), New York/Kennedy (JFK), New York/Newark (EWR) and New York/Islip (ISP)[2] from 2000 to 2003

The comparative time series analysis of flight delays across primary and secondary airports was extended to all multi-airport systems in the United States. It was found that over all cases, the percentage of operations delayed at the secondary airports was lower than at primary airports (Figure 89). From an airline management perspective, this measure is critical since these externalities are related to the costs incurred by the airlines. Since delays are lower at secondary airports, airlines and especially low-cost carriers, seeking low-cost structures are more likely to enter under-utilized airports.

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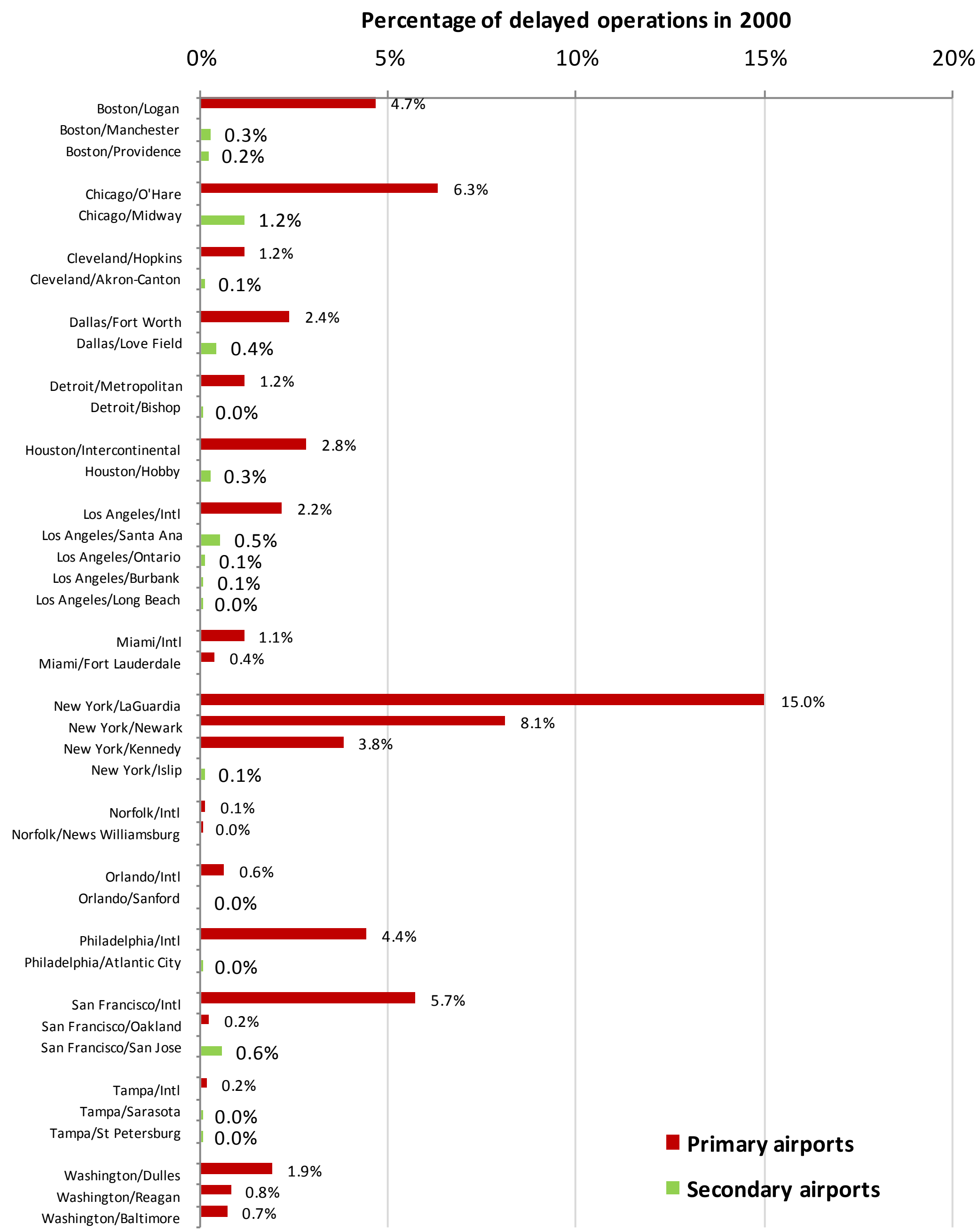
[1] Note: Southwest airlines entered service at Boston/Providence and Boston/Manchester in 1996 and 1998 respectively.

[2] Data source: US Federal Aviation Administration (FAA) OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: April 2008. Note: Due to the unavailability of delay data reported through the Airline Service Quality Performance (ASQP) database for secondary airports, OPSNET data was used for the comparative analysis. OPSNET data underestimates the true extent of delays but it sufficient for the purpose of this comparative analysis.



Data source: US Federal Aviation Administration (FAA) OPSNET data.
Note: By the nature of the definitions of delays and reporting process, OPNSET data underestimates the true extent of delays.
The use of this data in this figure is for airport to airport delay comparison purposes.

Figure 89: Percentage of flights delayed at primary and secondary airports in the United States in 2000[1]

[1] Data source: FAA OPSNET data, available at: http://aspm.faa.gov/opsnet/entryOPSNET.asp, last accessed: April 2008. Note: Due to the unavailability of delay data reported through the Airline Service Quality Performance (ASQP) database for secondary airports, OPSNET data was used for the comparative analysis.

The analysis of delays at primary airports was extended worldwide using qualitative pieces of evidence gathered in the process of the historical analysis of the airports that compose the 59 multi-airport systems (Table 20).

Table 20: Evidence of congestion of the primary airports influencing the emergence of a secondary airport

Airport Name	**Signs of Congestion**
Amsterdam/Schiphol	Runway and apron systems "near saturated at peak hours" in 2001
Boston/Logan	In the 1990s, Boston/Logan airport exhibited high level of delays and was repeatedly in the top 5 most delayed airports in the United States. High delays at Boston/Logan airport and the associated externalities made other airports in the region more attractive.
Chicago/O'Hare	Chicago/O'Hare exhibited high level of delays in 2003. In addition, the development of Chicago/Midway is constrained due to urban area encrochment. As a consequence, the need for additional capacity in the region is real. This need motivated the planning process of a new airport in Peotone, and is also the intiating factor of the potential emergence of Chicago/Gary located south east of the region.
Copenhagen/Kastrup	Runway and apron "near saturated at peak hours" in 2001
Frankfurt/Main	In the 1990s the need to add capacity at the airport was apparent and a plan to expand Frankfurt/Main through the addition of a fourth runway was set. However, the project was delayed several times due to environmental constraints in particular due to a mediation process that was engaged in 1999. The lack of available capacity at Frankfurt/Main was probably a determining factor in the emergence of Frankfurt/Hahn.
Gothenburg/Landvetter	Runway and apron "near saturated at peak hours" in 2001.
Mexico City/Intl	Runway, terminal and apron "near saturated most of the day" in 2001. Runway considerations limit the capacity of the airport .
Milan/Malpensa	Because of flight delays and inconvenience, Malpensa was assessed as one of the worst major airport in Europe by the EU oversight committee governing airports.
New York/LaGuardia	Slot restricted airport (with perimeter rule) established in 1969. As a consequence, the delays are maintained to lower levels than what they would be without demand management restrictions (cf. New York/LaGuardia in 2000, Chapter 2).
New York/Kennedy	In the recent years, New York/Kennedy has been exhibiting significant levels of delays and congestion (OPSNET 2008).
New York/Newark	New York/Newark chronically exhibits high level of delays as do other primary airports in the New York region.
Paris/Orly	The manifestation of delays is limited due to European airport capacity management (i.e. declared capacity), but the airport is severely constrained in terms of capacity and this was the motivation for constructing Charles de Gaulle airport.
San Francisco/Intl	Strong capactity constraints and congestion during IFR conditions (frequent in the Bay Area, with fog and limited visibility). In addition, the airport footprint is severly constraints and limit any future runway addition and expansion.
Stockholm/Bromma	Stockholm/Bromma was heavily congested in the 1960s and motivated the construction of Stockholm/Arlanda and the transfer to traffic
Toronto/Pearson	Runway, apron and terminal "near saturated at peak hours" in 2001.
Vancouver/Intl	Runway, apron and terminal "near saturated at peak hours" in 2001
Vienna/Intl	Runway, apron and terminal "near saturated at peak hours" in 2001. The capacity of the airport was limited due to runway capacity (i.e. intersecting runways). In addition, the Vienna was reaching capacity at the terminal level in the Non-Schengen area during departure peaks.
Washington/Reagan	Slot restricted airport (with perimeter rule) established in 1969. In addition, with a maximum runway length of 6,869 ft, Washington/Reagan could not host large commercial jets, that had to be accomodated at other airports in the region with longer runways (i.e. Washington/Dulles and Washington/Baltimore)

- ***Provision of airline entry incentives***

Cases of airline entry financial incentives are not easy to identify and find since the contracts are not necessarily published. However, in this analysis several cases have been identified through literature review and industry news analysis.

Incentives are generally provided to airlines through temporary discounts of landing fees and airport related charges.

The case of Copenhagen/Malmo illustrates the provision of such incentives. The LFV Group, that manages Copenhagen/Malmo, has an active airline entry (i.e. for new route) incentive provision program. Discount on new destinations are provided to stimulate traffic growth through discounts on take-off and terminal navigation charges and discount on passenger charges (excluding security charges) for a five year period.

The extent of the provision of airline entry incentive can be contested if it involves direct subsidies from the airport governing body and local or regional governments. The case of the entry of Ryanair at Brussels/South Charleroi illustrates this. The incentives provided by the government of Wallonia were identified as contravening the European Union's competition rules (European Parliament, 2007). In 2001, the government of Wallonia, which owns Brussels/South Charleroi, provided financial incentives to Ryanair in the form of reduced landing charges, reduced ground handling service charges, and support for the opening of Ryanair's base (Barbot, 2004). According to a 2004 report from the European Commission, under the proposed reduced charges agreement between the government of Wallonia and Ryanair, the landing fee and the handling charges were reduced by 50% and 90% respectively. In February 2004, the European Commission concluded that the agreement of reduced in charges was not compliant with article 87[1] of the Treaty. It was found that the reduced charges were incompatible with the common market and created distortion of the competition environment (e.g. with airlines operating at other airports in the region such as Brussels/Zaventem (BRU)).

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[1] Note: Article 87 of the European Commission Treaty (ex Article 92) states that "any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favoring certain undertakings or the production of certain goods shall, insofar as it affects trade between Member States, be incompatible with the common market". Source: European Commission, DG Competition, available at: http://ec.europa.eu/comm/competition/legislation/treaties/ec/art87_en.html, last accessed; March 2008.

- ***Role of the ownership and management of multi-airport systems***

Management and ownership can take several forms, from public to private forms. The process of privatization refers to the transfer of ownership from the public sector (e.g. local, regional or national government) to the private sector (e.g. private investment and/or management groups), while the reverse phenomenon is referred to as nationalization. Despite this simple definition, privatization and more specifically airport privatization can cover a wide range of forms (i.e. from partially to fully privatized entities). In addition, there is a distinction that needs to be emphasized between the privatization of the entity owning the airport (i.e. owner) and of that managing its operations (i.e. operator). As a result, the ownership and management of airports can take several forms. The following list[1] represents a list of the forms of ownership and management of airports;

- A. Government-owned; operated by Department or Agency of national government,
- B. Government-owned; operated by a municipal or regional Department or Agency,
- C. Government-owned; operated and managed by a private corporation,
- D. Operated by an independent Airport Authority, which is fully owned by municipal and/or regional and/or national government,
- E. Operated by an independent Airport Authority, which is fully owned by municipal and/or regional and/or national government but with minority private shareholders (some shares may be publicly traded),
- F. Privately-owned (fully or in majority, possibly with some or all shares publicly traded); operated as independent airport authority.

In the context of multi-airport systems, the analysis of the forms of ownership and management of airports needs to take into account the configuration of multi-airport system (i.e. role and number of airports in the system). As represented in Figure 90, the

[1] Source: (Odoni, 2002)

combinations of the forms of ownership and management of airports can vary according to the nature of the airports involved (i.e. primary versus secondary airports)[1].

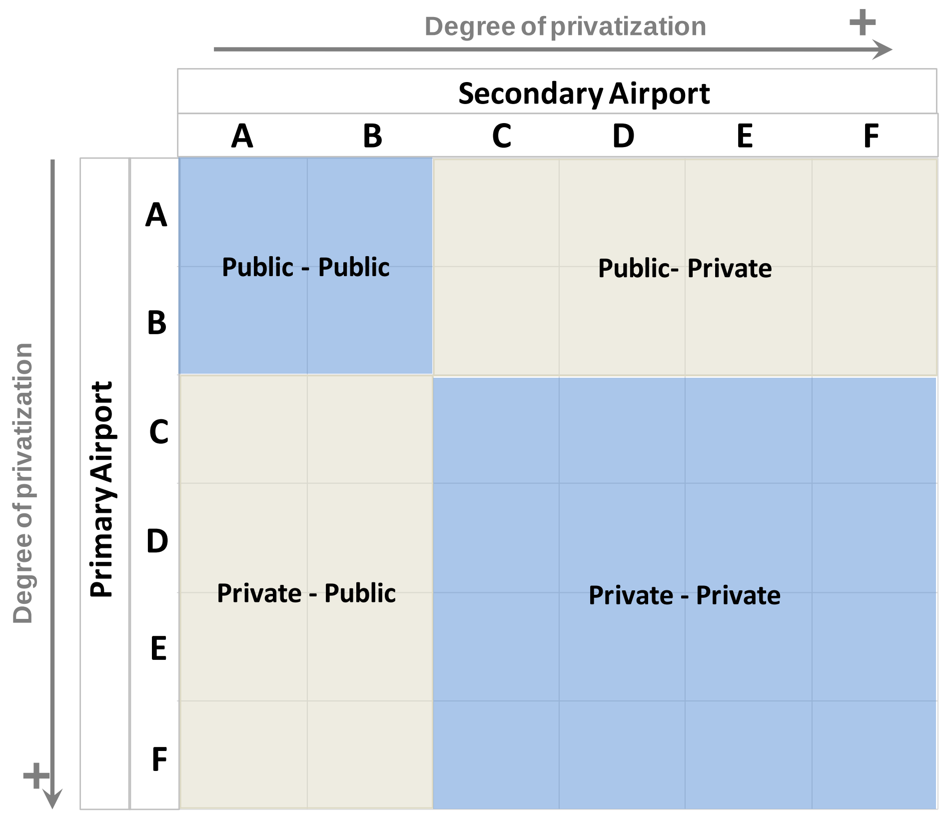

Figure 90: Combinations of forms of ownership and management of airports within multi-airport systems

All airports within a multi-airport system can be owned and operated by public entities (upper-left quadrant of Figure 90). Conversely, both type of airports can be operated by private entities (lower right corner), but also by a mix of private and public entities. In this case, the nature of the airport (primary versus secondary) was considered as an important factor since the dynamics and impacts of the privatization of the primary

[1] Note: In the case of multi-airport systems that were composed of two primary airports, the largest airport was categorized as primary and the smaller airport was categorized along the secondary airport axis of Figure 90. In addition, for multi-airport system systems that were composed of more than two significant airports, the most extreme cases of ownership and management of airports were used to plot the system in Figure 90 (cf. Figure 91 for applied framework). For instance, if a multi-airport system was composed of three significant airports that were owned and managed according to forms A, D and F, the combination of forms used to plot the system in Figure 90 were A and F.

(i.e. the incumbent) versus the secondary airport (i.e. the new entrant) were expected to differ.

In order to better understand the implications of the privatization of airports on the development of multi-airport systems, a systematic analysis of the forms of ownership and management of airports was conducted for the 59 cases of multi-airport systems (i.e. accounting for 144 airports in 26 different countries). For each airport, the owner and the operator were identified and matched with the list of forms of airport ownership and management (A through F). The full list of airports, owners and operators is presented in Appendix B.

Table 21 summarizes the distribution of forms of ownership and management. It was found that across the 59 cases of multi-airport systems, the most frequent form of ownership and management of airports was; "*D. Operated by an independent Airport Authority, which is fully owned by municipal and/or regional and/or national government*" which represents 32 % of the 144 airports. The two categories of semi-privatized and fully privatized forms of airport ownership and management; (*E. Operated by an independent Airport Authority, which is fully owned by municipal and/or regional and/or national government but with minority private shareholders -some shares may be publicly traded-* and *F. Privately-owned -fully or in majority, possibly with some or all shares publicly traded-*; operated as independent airport authority) represented respectively 17% and 15% of the 144 airports. The public forms of ownership and management (*A. Government-owned; operated by Department or Agency of national government* and *B. Government-owned; operated by a municipal or regional Department or Agency*), that are generally considered to be more traditional forms of ownership and management of airports, represented a combined 26% of all airports. Finally, the mixed form; *C: government-owned; operated and managed by a private corporation* represented only 8% of the cases.

Table 21 shows the breakdown of the distribution of the forms of ownership and management of airports for each of the six regions. This analysis permitted the identification of difference in the occurrence of the forms of ownership and management of airports across world regions. As shown on Table 21, the two most frequent forms in North America are the traditional "government-owned; operated by a municipal or regional Department or Agency” (B) and the more modern; “operated by an independent Airport Authority, which is fully owned by municipal and/or regional and/or national government” (D).

Table 21: Distribution of forms of ownership and management of airports

	World region					
Forms of ownership and management	Asia-Pacific	Europe	Latin America	Middle East	North America	Worldwide
A	4	5		2		11
B	1	4			22	27
C	2	6	2		3	13
D	3	19	7	3	14	46
E	7	16	2			25
F		21		1		22

In Europe, the profile of ownership and management of airports is different; a significant number of airports are owned and operated under the more modern form of ownership and management D through F (including a significant number of airports in the semi-privatized E and privatized F categories). There are still a few airports that are owned and operated under the more traditional (public) forms, mostly in Northern Europe (e.g. Sweden, Norway). In the Asia-Pacific region, the dominant forms of ownership and management are D-E-F with a few public airports (A) mostly in Japan. Multi-airport systems in Latin America, Middle East and Africa tend to be operated under the categories D through F (with the exception of two airports in the Middle East –Dubai- that are owned and operated under the “government-owned; operated by Department or Agency of national government” (A) form.

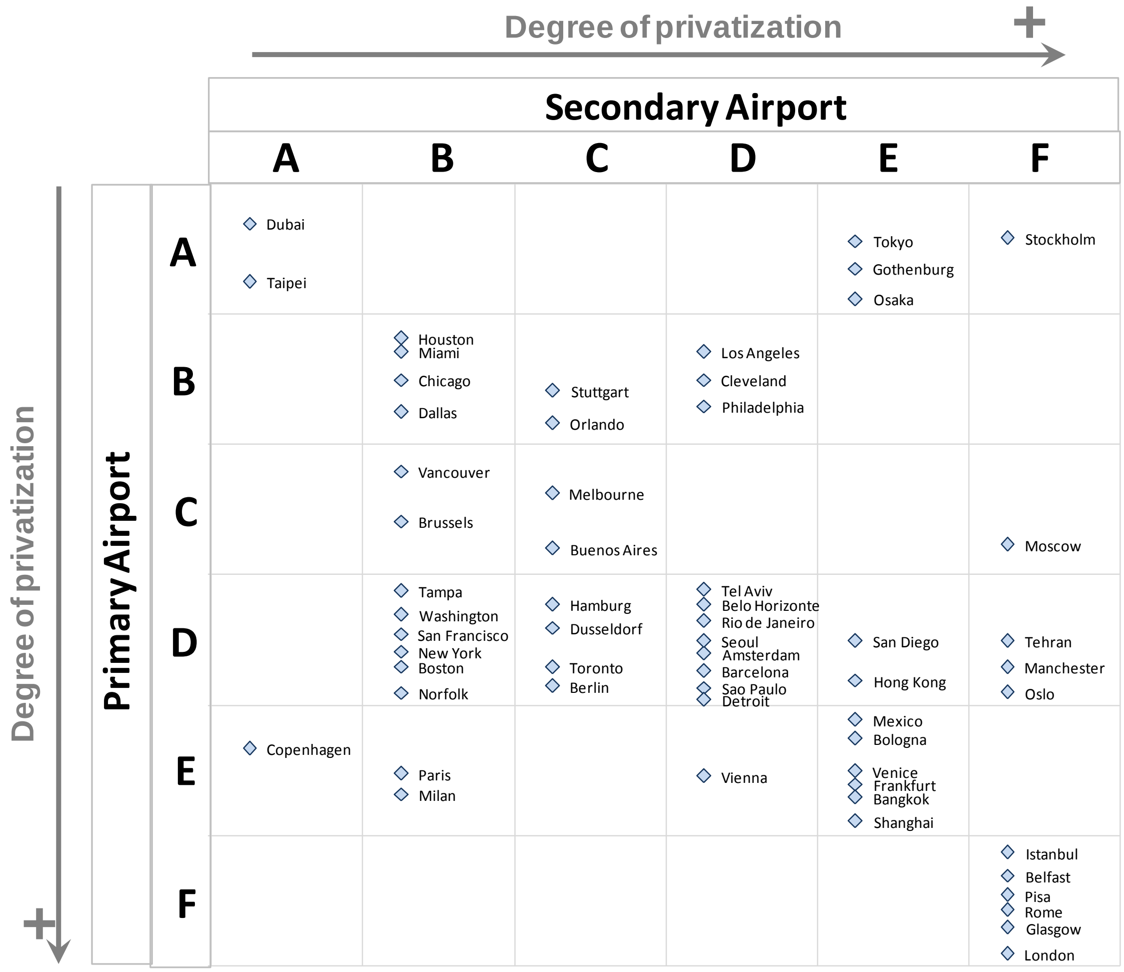

Figure 91: Combinations of forms of ownership and management of airports across the 59 cases of multi-airport systems worldwide

The analysis of the forms of ownership and management of airports showed a wide array of combinations of these forms of ownership and management of airports. The effects of privatization differ according to the configurations of multi-airport system (i.e. whether it is the primary airport or secondary airport that is privatized) and the geographic location of these multi-airport systems. In some cases, the privatization of airports had positive effects on the development of multi-airport systems through the provision of capital for the development of under-utilized airports that result in the successful emergence into secondary airports. In Europe, a dominant pattern was observed; privatization of under-utilized airports -especially converted military bases-and the successful attraction of low-cost carriers that allow the airport to emerge as a successful secondary airport that competes or complements the service offered at the primary airport. More generally, the privatization of airports in the context of multi-airport systems potentially offsets the monopolistic situation of single airport systems and allows the private sector to share the risk of airport development, not necessarily justified and feasible by the local public sector. While several cases of successful emergence of new secondary airports were observed and analyzed, the privatization and investment in non-utilized airports comes with significant risk due to volatility of traffic (i.e. airlines entries and exits).

Subsequent and non-exhaustive analyses of forms of ownership and management of single-airport systems in transition (cf. Section 9.1) showed that privatization –especially of major airports- can limit the development of multi-airport systems. The use of regulatory tools to influence traffic distribution within airports serving a region can limit the development of multi-airport systems. For instance in India, the 1997 Indian Airport Infrastructure Policy was designed to limit the construction of new airports within 150 km (i.e. 93 miles) of existing major airports (Task Force on Infrastructure of India, 2008). This policy put in place to attract and protect airport investments into existing airports limits the development of new multi-airport systems[1].

[1] Note: In recognition of the need to develop multi-airport systems to meet growing demand for air transportation in India, the perimeter rule was amended in April 2008.

8.3 Dynamics and Factors Influencing the Construction and Transfer of Traffic to New Airports

8.3.1 Brief description of the model

The construction of new airport and transfer of traffic is influenced by a set of sub-dynamics and factors. First, the construction of a new airport is generally a long and complex process involving multiple stakeholders. It starts with the identification of the need for a new airport, is then followed by a planning process that involves the selection of a site and ultimately results in a master plan. The development is then carried out followed by the construction and delivery. In some cases, once the airport is operational, the second phase of the general dynamic involves the transfer of traffic to the new airport. Several strategic solutions exist to make the transfer successful and sustainable.

The following section presents the detailed dynamics and factors that govern the evolution of multi-airport systems through this path of construction of new airports.

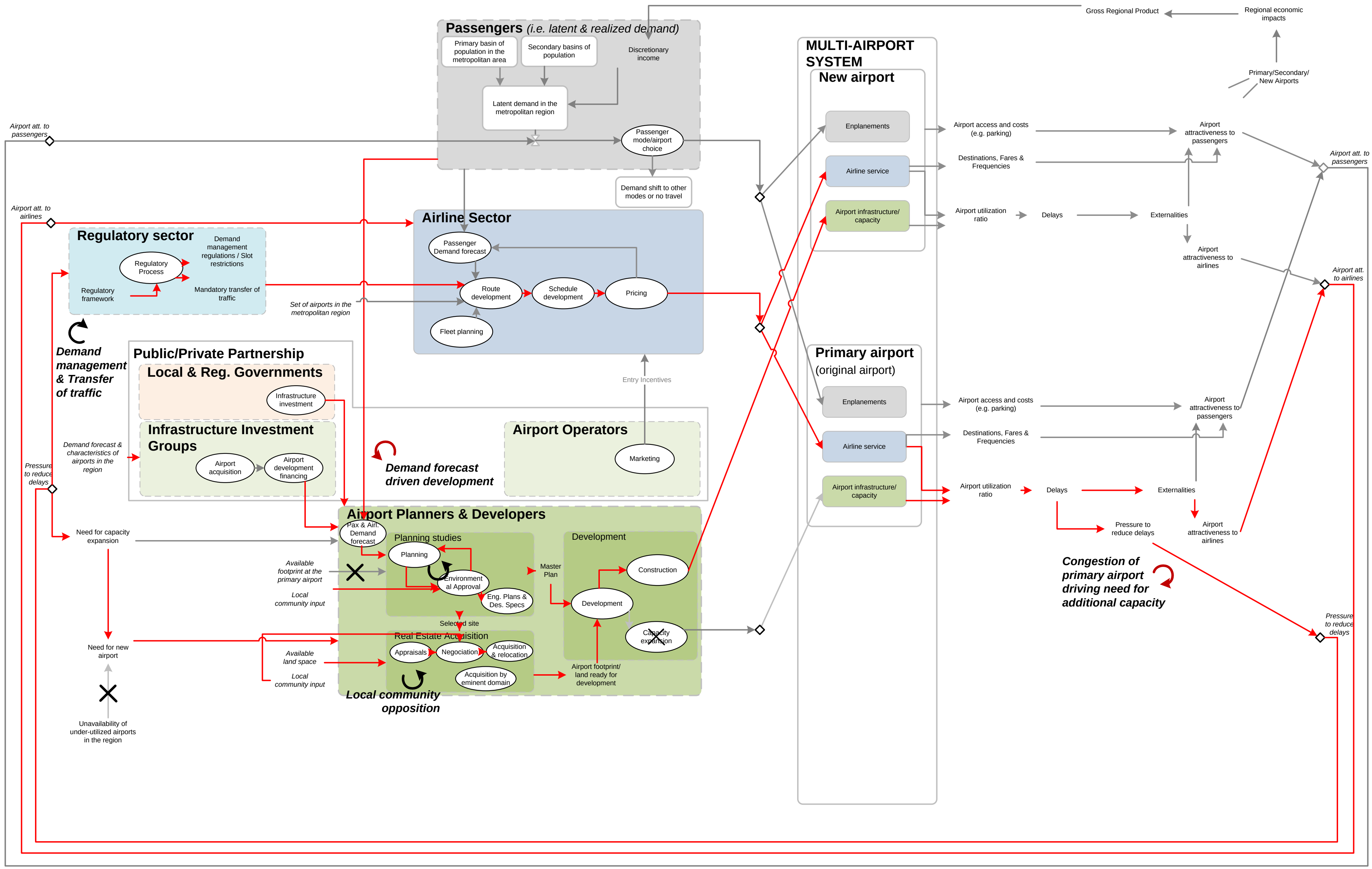

Figure 92: Feedback model of the dynamics and factors influence the construction of new airports

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a. Sub-dynamics

- ***Identification of a need to build a new airport***

As shown on Figure 92, the construction of a new airport arises from the need for additional airport capacity in the region. This need can be the result of observed capacity shortfall at the existing primary airport (i.e. coupled with the inability to expand the airport) or limited capabilities of the existing airports (e.g. runway length requirements), (cf. Model, Figure 92, *Congestion of the primary airport driving the need for additional capacity* loop).

- ***Planning, Financing and Construction of new airport***

This need for a new airport in the metropolitan region and the decision to proceed with this process leads to the planning that is then followed by the construction process. The process of airport planning can be blocked or delayed by local community input and opposition (cf. Model, Figure 92, *Local community opposition* loop).

- ***Transfer of traffic/Entry of carriers***

Regulatory processes have a significant role in the way traffic distributed in the case of the construction of a new airport and partial or total transfer of traffic from an original primary airport to the new airport. While the original primary airport can be successfully closed, it is generally difficult to do so (de Neufville, et al., 2003).

New airports are generally located further away from the city center than the original primary airport and keeping the original primary airport open makes the new airport less attractive for airlines and creates competition and market access problems. Regulatory solutions can be employed in these cases in order to force the distribution of traffic. (cf. Model, Figure 92, *Transfer of traffic* loop). These mechanisms can involve, mandatory transfer of traffic, passed through local or regional legislations, or financial incentives or penalties resulting in differential costs of operation between airports, making one airport more attractive than another from a cost standpoint.

These regulatory tools can sometimes be effective to preserve the original airports (i.e. by avoiding to close it) while ensuring the successful emergence of a new primary airport.

b. Factors influencing the construction of new airports

- ***Forecast of future passenger traffic within the metropolitan region***

The projection of demand for air transportation within the region is one of the key initiating factors influencing the anticipatory dynamic of construction of a new airport (cf. Model, Figure 92, *Demand forecast driven development* loop).

- ***Congestion of primary airports***

For the same reasons as those mentioned in the case of the emergence of a secondary airport the congestion of the primary airport can be an initiating factor influencing the dynamic of construction of a new airport. However, unlike the initiating factor of forecast of the future traffic (i.e. to identify the future need of an airport), the congestion of the primary airport is the cause of a reactive process more than an anticipatory process (cf. Model, Figure 92, *Congestion of primary airport driving need for additional capacity* loop).

- ***Limitations of existing airports***

The lack of adequate physical airport infrastructure such as runway length can also be a reason for initiating the process of planning and construction of new airports in a metropolitan region. Changes in aircraft fleet (e.g. historically the shift from propeller aircraft to jet propelled aircraft) can impose new requirements on airport infrastructure.

- ***Lack of availability of airport infrastructure***

While the obvious condition for the process of emergence of secondary airport to emerge (i.e. from an existing under-utilized airport) was the availability of existing under-utilized airports in the region, the lack of such airports can drive the need for the construction of new airports. Areas of the world where the set of under-utilized airports is weak are more likely to exhibit an evolution of multi-airport systems through the construction of new airports.

- ***Availability and acquisition of land area in the metropolitan region***

As shown on Figure 92, the overall process of construction of a new airport in a region requires access to land area sufficiently vast to develop an airport. The degree of success of acquisition of the necessary land depends on three key factors; (1) usage of the land (e.g. agricultural, residential, commercial, etc.), (2) the fragmentation and ownership of the land required and (3) the presence of natural habitats on the land. The overall process can also be influenced by local community input and potentially delayed or blocked (cf. Model, Figure 92, *Local community opposition* loop).

8.3.2 Results from the multiple-case study analysis

a. Factors influencing the construction of new airports

- ***Congestion and physical limitations of the primary airports***

The congestion and physical limitations of the primary airport that acted as initiating factors influencing the construction of a new airport was found in the following cases.

Table 22: Evidence of congestion and physical limitations of primary airports that motivated the construction of a new airport in a metropolitan region

World Region	Airport name	Congestion and physical limitations of the primary airports
Asia/Pacific	Bangkok/Don Mueang	Don Mueang airport was assessed by Airport of Thailand as; overloaded and not expandable .
	Hong Kong/Kai Tak	Hong Kong/Kai Tak's footprint was constrained by urban development and terrain limitations.
	Osaka/Itami	In the 1970s, the potential expansion of Osaka/Itami was limited due to urban encroachment and opposition from local communities. Due to the expansion of Osaka/Kansai and the construction of Osaka/Kobe additional capacity is available at Itami.
	Seoul/Gimpo	The airport could not be expanded to accommodate projected traffic growth in the region. In the early 2000s, the airport was congested.
	Shanghai/Pudong	In the 1990s, the projections of growing demand in the region coupled with limited expansion at Shanghai/Hongqiao due to urban development surrounding the airport motivated the need for a second airport in the region.
	Taipei/Songshan	Taipei/Songshan was constrained by capacity in the 1970s. In addition, the runways (i.e. the longest runway today is 8,547 ft long) were too short to accommodate wide-body jets.
	Tokyo/Haneda	Tokyo/Haneda was becoming congested in the 1960s and it was impractical to expand the airport (i.e. large amounts of land would have needed to be reclaimed on the harbor).
Europe	Gothenburg/Torslanda	Gothenburg/Torslanda was constrained by its footprint and expansion was needed to accommodate larger aircraft in the 1970s.
	Oslo/Fornebu	Oslo/Fornebu had only one operational runway and no room for expansion, with sea constraints
	Paris/Orly	Paris/Orly was constrained by urban development limiting the ability to expand the airport footprint.
	Rome/Ciampino	Rome/Ciampino has one single runway and its expansion is constrained. Even after its reemergence phase, the airport is still constrained and local community pressure attempted to curb traffic in 2007.
	Stockholm/Bromma	Stockholm/Bromma was heavily congested in the 1950s and had limited expansion capabilities (i.e. surrounded by dense urban development).
Latin America	Belo Horizonte/Pampulha	Belo Horizonte/Pampulha was congested in the 1970s-1980s which motivated the development of the primary airport in the region; Belo Horizonte/Neves. The expansion of the footprint of the airport is also heavily constrained by surrounding urban development.
	Buenos Aires/Newbery	Buenos Aires/Newbery is constrained by urban development. As a result it was not possible to expand it.
	Rio de Janeiro/Santos Dumont	The airport was built on reclaimed land, leaving no space for expansion. The airport is heavily congested.
	Sao Paulo/Congonhas	Sao Paulo/Congonhas's expansion is limited due to its footprint and has short runways (i.e. longest runway 6,365 ft long). These runways constraints motivated the construction of Viracopos in the 1960s. Sao Paulo/Congonhas remained congested in the 1980s which motivated the construction of Sao Paulo/Guarulhos International in 1985 and partial transfer of traffic.
M. East	Tehran/Mehrabad	Tehran/Mehrabad faced congestion and expansion limitations.
North America	Chicago/Midway	In the mid 1940s, Midway reached saturation. In the 1950s, it was also constrained by its infrastructure (i.e. runways too short) that prohibited the first generation of jet airplanes to access the airport.
	Dallas/Love Field	Dallas/Love Field faced capacity constraints and expansion constraints.
	Houston/Hobby	In the 1960s, Houston/Hobby faced land limitations and constraints that motivated the construction of Houston/Intercontinental.
	Washington/Reagan	Washington/Reagan's footprint is heavily constrained due to urban development on the west side and the Potomac River on other sides. There is no available space in the current footprint to add runway capacity.

- ***Forecast of future passenger traffic within the metropolitan region***

Gross Domestic Product (GDP) is driving air transportation activity and conversely (cf. Chapter 2; background on the air transportation system). The projected rate of growth of traffic in a metropolitan region influences directly the traffic forecasts used for airport planning purposes. As a consequence, regions where the projections of traffic show large increase in traffic (and where the existing airport infrastructure in the region is limited) are more likely to exhibit the dynamic of construction of new airports. Conversely, more mature regions that are growing according to slower rates that require marginal airport capacity addition are more likely to exhibit the dynamic of emergence of a secondary airport through the utilization of an under-utilized existing airport.

Countries where secondary airports have emerged were in general those where slower growth rate of air traffic was observed. Conversely, countries where high annual growth rate of traffic are observed or anticipated exhibit predominantly the mechanism of construction of new airports.

Based on the historical analysis of the airports within multi-airport systems, it was found that in Europe and in North America, existing primary and secondary airports were constructed prior to World War II (Figure 93). Whereas in Asia-Pacific, the major phase of construction of airports is more recent (i.e. 1970s and 1990s/2000s). For airport constructed in the 1990s and 2000s, the projection of demand for these metropolitan regions was key factors in the initiation of the planning and construction process (e.g. Osaka/Kansai, Hong Kong/Intl, Shanghai/Pudong, Guangzhou/Baiyun, and Bangkok/Suvarnabhumi).

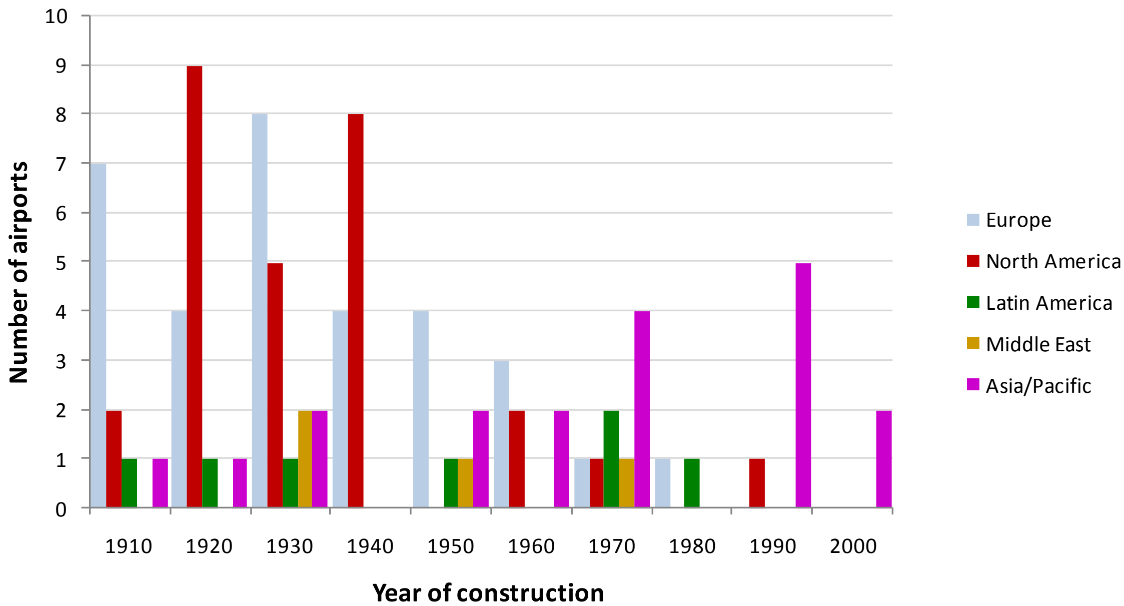

Figure 93: Histogram of the year of construction of primary and secondary airports within multi-airport systems (by world regions)

Role of regulatory and political factors in the closure of airports and mandatory transfer of traffic

Regulatory factors played a significant role in the way traffic distributed in the case of the construction of a new airport and partial or total transfer of traffic from an original primary airport to the newly constructed airport. While in few cases the original primary airport was successfully closed (e.g. Denver/Stapleton in 1995, Oslo/Fornebu in 1998, Hong Kong/Kai Tak in 1998, Athens/Ellenikon in 2001), it is generally difficult to do so. Given that in all the cases in the study, the new airport was located further away from the city center than the original primary airport, keeping an original primary airport open makes the new airport less attractive for airlines and creates competition and market access problems. Regulatory solutions were often employed in these cases in order to force the distribution of traffic. In the United States, the Wright Amendment limited Southwest Airlines' operations at Dallas/Love Field (DAL) in order to ensure transfer of traffic to Dallas/Fort Worth (DFW) illustrates the role and the impact of such regulatory and political factors on the evolution of multi-airport systems. These regulatory tools can be effective to preserve the original airports (i.e. by avoiding to close it) while ensuring the successful emergence of a new primary airport.

8.4 Summary of the Identification of Dynamics and Factors across the 59 cases of Multi-Airport Systems

Details for each case study are presented in Appendix C. Table 23 summarizes the observations of the dynamics and factors that played a role in the evolution of the 59 multi-airport systems.

Table 23: Summary of factors influencing the dynamics of multi-airport systems

North America

	Boston	Los Angeles	Miami	Orlando	San Francisco	Tampa	Toronto	Vancouver	Chicago	Dallas	Houston	New York	Washington	Cleveland	Philadelphia	Detroit	San Diego	Norfolk
Construction of airport									●	●	●	●	●					
Utilization of existing airport	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Secondary basin of population close to the emerged airport	■	■	■	■	■	■	■					■	■	■	■	■	■	■
Congestion of the primary airports influencing the emergence of a secondary airport	■				■		■	■	■			■	■					
Congestion and physical limits of primary airport airport influencing the construction of new airports									■	■	■	■	■					
Secondary airports converted from military airfields				■			■	■							■			
Entry of low cost carriers	■	■	■		■		■	■	■	■	■	■	■	■	■	■	■	
Transfer of traffic to a new airport									■	■	■	■						
Decision to close initial airport																		
Airline Entry Incentives																		

Europe

	Amsterdam	Barcelona	Belfast	Bologna	Brussels	Copenhagen	Dusseldorf	Frankfurt	Glasgow	Gothenburg	Hamburg	Manchester	Milan	Oslo	Rome	Stuttgart	Venice	Vienna	Moscow	Paris	Berlin	London	Stockholm	Istanbul	Pisa
Construction of airport																			●	●	●	●	●	●	
Utilization of existing airport	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Secondary basin of population close to the emerged airport	■			■		■	■				■	■	■					■							■
Congestion of the primary airports influencing the emergence of a secondary airport	■					■		■		■			■					■		■			■		
Congestion and physical limits of primary airport airport influencing the construction of new airports										■				■	■					■			■		
Secondary airports converted from military airfields		■				■	■	■	■	■	■		■			■	■			■		■	■		
Entry of low cost carriers	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■			■		
Transfer of traffic to a new airport																				■	■	■	■		
Decision to close initial airport														■							■				
Airline Entry Incentives					■	■																			

Asia/Pacific

	Melbourne	Bangkok	Hong Kong	Osaka	Seoul	Shanghai	Taipei	Tokyo
Construction of airport		●	●	●	●	●	●	●
Utilization of existing airport	●	●						
Secondary basin of population close to the emerged airport	■							
Congestion of the primary airports influencing the emergence of a secondary airport								
Congestion and physical limits of primary airport airport influencing the construction of new airports		■	■	■	■	■	■	■
Secondary airports converted from military airfields	■							
Entry of low cost carriers	■	■						
Transfer of traffic to a new airport		■	■	■	■	■	■	■
Decision to close initial airport		■						
Airline Entry Incentives								

Latin America

	Mexico	Belo Horizonte	Buenos Aires	Rio de Janeiro	Sao Paulo
Construction of airport		●	●	●	●
Utilization of existing airport	●				
Secondary basin of population close to the emerged airport	■				
Congestion of the primary airports influencing the emergence of a secondary airport	■				
Congestion and physical limits of primary airport airport influencing the construction of new airports		■	■	■	■
Secondary airports converted from military airfields					
Entry of low cost carriers	■				
Transfer of traffic to a new airport		■	■	■	■
Decision to close initial airport					
Airline Entry Incentives					

M.E.

	Dubai	Tehran	Tel Aviv
Construction of airport		●	
Utilization of existing airport	●		●
Secondary basin of population close to the emerged airport			
Congestion of the primary airports influencing the emergence of a secondary airport			
Congestion and physical limits of primary airport airport influencing the construction of new airports		■	
Secondary airports converted from military airfields			
Entry of low cost carriers	■		
Transfer of traffic to a new airport		■	
Decision to close initial airport			
Airline Entry Incentives			

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CHAPTER 9

IMPLICATIONS FOR THE FUTURE DEVELOPMENT OF MULTI-AIRPORT SYSTEMS AND AIR TRANSPORTATION SYSTEM

The key questions and implications for the future development of multi-airports are; (1) the location of future development of multi-airport systems, (2) how the context of these countries (i.e. state of air transportation infrastructure, future needs, policies, etc.) may influence future development of these systems and (3) how the lessons learned from this study can be used to better plan, operate and manage these systems. This section is structured around these key questions.

In the first part of this chapter, a shorter term view of the evolution of multi-airport systems with the analysis of single airport systems in transition. The long term needs and future airport infrastructure adequacy are then assessed at the country level. The analysis is refined to focus on metropolitan regions that are likely to exhibit growth of demand for air transportation and where additional airport capacity may be needed.

Section 6.4.2 showed that the role of low-cost carriers was substantial in the dynamics of emergence of secondary airports. As an extension to this analysis, the implications of worldwide trends in the development of low-cost carriers are assessed in this chapter.

Finally, the implications of this research for future airport infrastructure planning and development of multi-airport systems are assessed.

9.1 Short to Medium Term Development of Multi-Airport Systems

In parallel to the identification and detailed analysis of existing multi-airport systems, an analysis of single-airport systems in transition was also performed. While the airport systems presented in Table 6 are composed of two or more significant airports that serve commercial passenger traffic in a metropolitan region, a non-exhaustive set of single-airport systems in transition were also identified (Figure 94). These systems had either plans or initial construction of new high capacity airports or had emerging secondary airports in the metropolitan region[1].

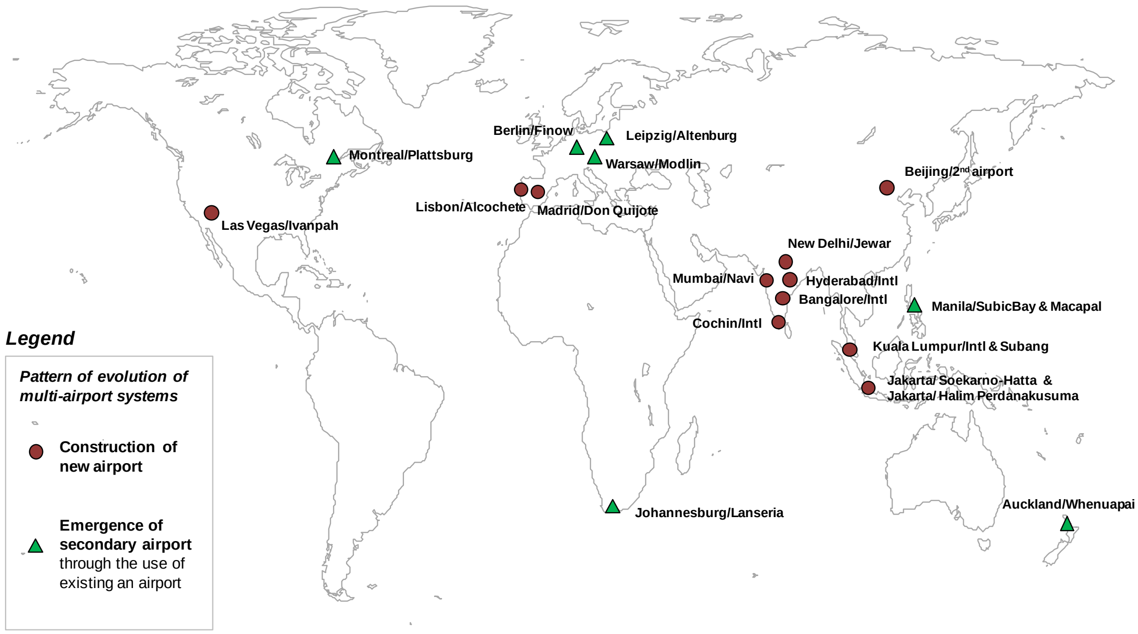

Figure 94: Worldwide geographical distribution of single-airport systems in transition

As shown in Figure 94, a significant number of the single-airport systems in transition are located in Asia-Pacific, corresponding mostly to airport systems where a new high capacity airport is under construction or in future development. The five cases of single-airport systems in Europe also represent airport systems in transition through both the mechanism of construction on new airports and emergence of secondary airports. The case of Montreal in North America is an interesting case of failure to develop a second airport through the mechanism of construction of new airports (i.e. Montreal/Mirabel). This system now shows indications of potential emergence of a secondary airport in this metropolitan region with the entry of airlines at Montreal/Plattsburgh, located 58 miles south of Montreal (i.e. in the United States).

[1] Note: Emerging secondary airport: airport part located in the metropolitan region that serves less that serves less than 500,000 passengers per year or 1% of the traffic and exhibits early signs of emergence (i.e. airport infrastructure improvements, entry of a low-cost carrier).

Table 24: Single-airport systems in transition worldwide

World region	Country	Metropolitan Region	Dynamics affecting these single-airport systems in transition
Africa	South Africa	Johannesburg	Potential emergence of a secondary airport (i.e. Johannesburg/Lanseria)
Asia/Pacific	China	Beijing	Construction of a second airport (i.e. expected to start in 2010).
	India	Bangalore	Construction of a new airport in 2008 (Bangalore/Intl) and the original airport (Bangalore/HAL) may remain open and become a secondary airport.
	India	Cochin	Construction of a new airport and transfer of traffic with the original serving domestic traffic
	India	Hyderabad	Construction of a new airport opened 2008 (Rajiv Gandhi International) and the original airport that may become a secondary airport (Begumpet)
	India	Mumbai	Original airport (i.e. Mumbai/Intl) with the potential construction of a new high capacity airport (i.e. Mumbai/Navi)
	India	New Delhi	Original airport with the potential construction of a new high capacity airport (i.e. New Delhi/Noida in Jewar)
	Indonesia	Jakarta	Construction of a new airport and transfer of traffic with the original serving as a potential secondary airport
	Malaysia	Kuala lumpur	Construction of a new airport and transfer of traffic with the original serving domestic traffic (Subang)
	New Zealand	Auckland	Potential emergence of a secondary airport (i.e. Auckland/Whenuapai)
	Philippines	Manila	Primary airport (Manila/Aquino) with the potential emergence of two secondary airports (i.e. Manila/Subic Bay and Manila/Macapagal)
Europe	Germany	Berlin	Potential growth of traffic at a secondary airport (i.e. Berlin/Finow), despite the consolidation of the three major airports in the region (i.e. Berlin/Tegel, Berlin/Tempelhof and Berlin/Schoenfeld) into one single airport
	Germany	Leipzig	Potential growth of traffic at a secondary airport (i.e. Leipzig/Altenbourg)
	Poland	Warsaw	Military airfield with plans to transfer it to civil status and serve low-cost carriers (i.e. Warsaw/Modlin)
	Portugal	Lisbon	Construction of a new airport (i.e. Lisbon/Aclochete)
	Spain	Madrid	Construction of a new airport (i.e. Madrid/Don Quijote)
North America	Canada	Montreal	Unsucessfull sustained establishment of a primary airport (i.e. Montreal/Mirabel) through the construction and transfer of traffic. All traffic was transferred back to Montreal/Turdeau. Montreal/Plattsburgh located 57 miles south of Montreal is exhibiting early signs of emergence (e.g. entry of Allegiant Airlines, CapeAir).
	United States	Las Vegas	Potential construction of a new airport in the Invanpah Valley

Table 24 shows a set of airport systems for which a secondary airport is likely to emerge or plans to construct a new airport exist. Table 24 indicates that most of the single-airport systems in transition are located in Asia-Pacific, corresponding mostly to airport systems where a new high capacity airport is under construction or in future development. In addition, multi-airport systems in Europe continue to evolve through the emergence of new secondary airports, especially as European low-cost carrier expands towards Eastern Europe (i.e. Warsaw, Leipzig).

9.2 Future Airport Infrastructure Adequacy and Long Term Needs

In order to assess where regions of the world may exhibit future development of multi-airport systems, there is the need to investigate where future demand for air transportation is likely to emerge and how the airport infrastructure in these countries is able to accommodate anticipated growth of demand. Figure 95 shows Revenue Passenger-Kilometers per Capita (RPK per Capita) versus Gross Domestic Product per Capita in 2004. As Gross Domestic Product (GDP) per Capita increases in developing and emerging countries, demand for air transportation is expected to increase accordingly. In Figure 95, the size of the bubbles is proportional to the population in each country and is indicative of the future potential demand for transportation in nominal terms. From Figure 95, as GDP grows in China and India, significant demand for air transportation and traffic will be generated.

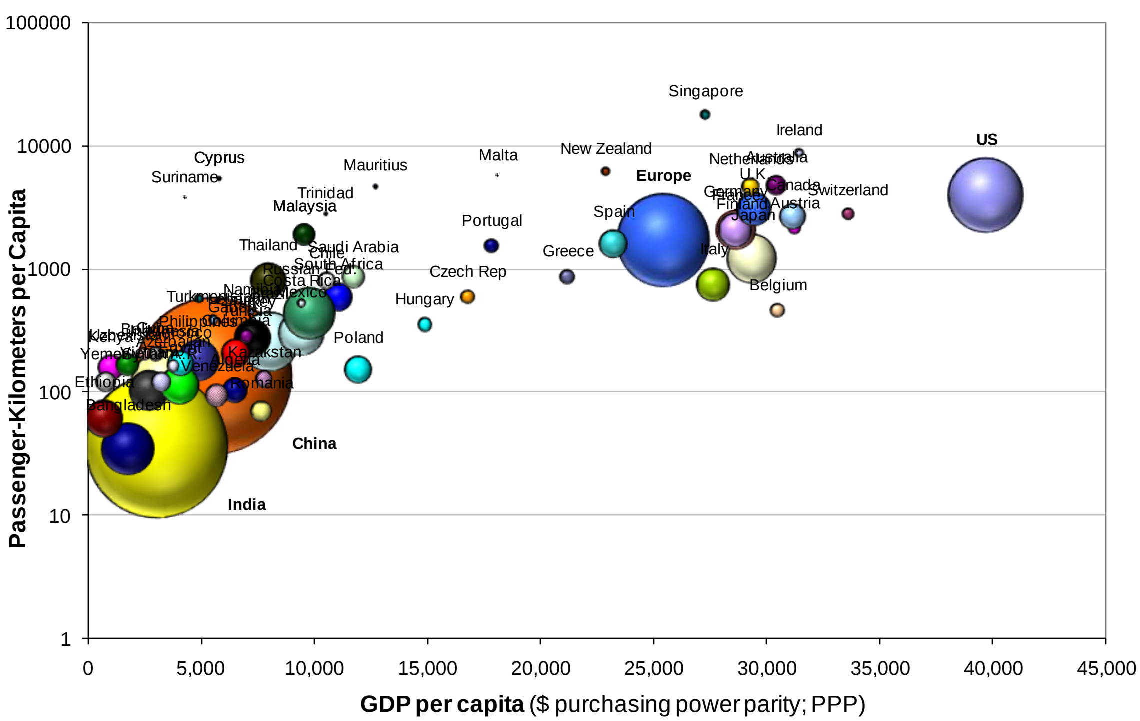

Figure 95: Revenue Passenger Kilometers (RPK) per capita versus Gross Domestic Product (GDP) per capita in 2004[1]

[1] Data source: Revenue Passenger Traffic (RPK) from International Civil Aviation Organization (ICAO): Annual Review of Civil Aviation 2005. Montreal, Canada and population and (CIA) World Fact Book database, available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ee.html, last accessed: January 2008.

The analysis of the adequacy of airport infrastructure and the construction of the regional airport system capacity coverage charts (Figure 86) showed the great diversity in the ability of different world regions, and different countries, to accommodate future demand.

In order to generally assess the adequacy of airport capacity and potential demand (i.e. latent demand), a comparative analysis of the ratio of population over number of existing airports within all countries was performed. Table 25 shows the list of countries (with population greater than 10 million) ranked by decreasing ratio of population over number of existing airports. With large ratios of population over airport infrastructure and high population numbers, China and India will require significant future development of airport infrastructure as their GDP grows. In contrast, the United States and Europe generally have larger number of existing airports that can accommodate future growth through the emergence of new secondary airports.

Table 25: List of countries and regions ranked by decreasing ratio of population over number of existing airports with runways longer than 5000ft[1]

Country	Population (est. 2007) in millions	Airports with paved with runways longer than 5000 ft	Ratio of Population to Airports (millions)
Bangladesh	150	9	16.72
India	1,130	141	8.01
Nigeria	135	28	4.82
China	1,322	321	4.12
Indonesia	235	68	3.45
Pakistan	165	68	2.42
Japan	127	87	1.46
Brazil	190	196	0.97
Mexico	109	122	0.89
Europe (27)	490	1013	0.48
Russia	141	379	0.37
United States	301	1836	0.16

The previous analysis conducted at the country level provides insights on the general capabilities of countries to meet latent demand given their existing airport infrastructure. In order to identify metropolitan regions around the world where the need for future development of multi-airport systems may emerge, a comparable analysis of demand and airport infrastructure capabilities in metropolitan regions with more than 1 million residents was performed. Table 26 shows the top 60 metropolitan regions ranked by

[1] Note: Analysis does not account for relative spatial distribution of existing airports to population
Data source: CIA World Fact Book database, available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ee.html, last accessed: January 2008.

decreasing population and the status of the airport system serving the region (i.e. single-airport system versus multi-airport system[1]). As shown on Table 26, a total of 27 metropolitan regions worldwide with significant local population that have not yet transitioned to multi-airport systems or are in the process of transitioning. A significant number of these regions are located in Asia where, as GDP and discretionary income of residents in these metropolitan regions grow, demand for air transportation will increase and put pressure on the existing airport infrastructure and possibly trigger the transition to multi-airport systems.

[1] Note: MAS: Multi-Airport System, SAS: Single-Airport System

Table 26: Top 60 metropolitan regions worldwide in terms of metropolitan region population

Metropolitan Population Rank	Metropolitan Area	Country	Population in the Metropolitan Area	Existence of a multi-airport system
1	Tokyo	Japan	34,997,000	MAS
2	Mexico City	Mexico	18,660,000	MAS
3	New York	United States	18,252,000	MAS
4	Sao Paulo	Brazil	17,857,000	MAS
5	Mumbai	India	17,431,000	SAS in Transition
6	New Delhi	India	14,145,000	SAS in Transition
7	Calcutta	India	13,805,000	
8	Buenos Aires	Argentina	13,047,000	MAS
9	Shanghai	China	12,759,000	MAS
10	Jakarta	Indonesia	12,295,000	SAS in Transition
11	Los Angeles	United States	12,018,000	MAS
12	Dhaka	Bangladesh	11,560,000	
13	Osaka	Japan	11,243,000	MAS
14	Rio de Janeiro	Brazil	11,214,000	MAS
15	Karachi	Pakistan	11,078,000	
16	Beijing	China	10,847,000	
17	Cairo	Egypt	10,834,000	
18	Moscow	Russian Federation	10,468,000	MAS
19	Manila	Philippines	10,352,000	SAS in Transition
20	Lagos	Nigeria	10,103,000	
21	Paris	France	9,794,000	MAS
22	Seoul	South Korea	9,713,000	MAS
23	Istanbul	Turkey	9,371,000	MAS
24	Tianjin	China	9,271,000	
25	Chicago	United States	8,567,000	MAS
26	Lima	Peru	7,898,000	
27	London	United Kingdom	7,619,000	MAS
28	Bogota	Colombia	7,289,000	
29	Tehran	Iran	7,190,000	MAS
30	Hong Kong	China	7,049,000	MAS
31	Chennai (Madras)	India	6,691,000	
32	Essen	Germany	6,559,000	
33	Bangkok	Thailand	6,486,000	MAS
34	Bangalore	India	6,140,000	SAS in Transition
35	Lahore	Pakistan	5,989,000	
36	Hyderabad	India	5,863,000	SAS in Transition
37	Wuhan	China	5,652,000	
38	Baghdad	Iraq	5,620,000	
39	Santiago	Chile	5,477,000	
40	Saint Petersburg	Russian Federation	5,285,000	
41	Kinshasa	Congo	5,276,000	
42	Philadelphia	United States	5,260,000	MAS
43	Miami	United States	5,215,000	MAS
44	Riyadh	Saudi Arabia	5,125,000	
45	Madrid	Spain	5,103,000	SAS in Transition
46	Belo Horizonte	Brazil	5,047,000	MAS
47	Shenyang	China	4,881,000	
48	Toronto	Canada	4,879,000	MAS
49	Ahmadabad	India	4,869,000	
50	Ho Chi Minh City	Vietnam	4,850,000	
51	Chongqing	China	4,847,000	
52	Dallas	United States	4,445,000	MAS
53	Barcelona	Spain	4,406,000	MAS
54	Khartoum	Sudan	4,285,000	
55	Sydney	Australia	4,273,000	
56	Singapore	Singapore	4,252,000	
57	Boston	United States	4,212,000	MAS
58	Pune (Poona)	India	4,143,000	
59	Houston	United States	4,117,000	MAS
60	Washington	United States	4,098,000	MAS

As a complement to Table 26, Table 27 shows the remaining list of metropolitan regions beyond the top 60 metropolitan regions (in terms of population).

Table 27: List of metropolitan regions with multi-airport systems or single airport systems (ranked by increasing rank based on metropolitan region population)

Metropolitan Population Rank	Metropolitan Area	Country	Population in the Metropolitan Area	Existence of a multi-airport system
61	Milan	Italy	4,063,000	MAS
64	Detroit	United States	3,950,668	MAS
65	Guangzhou	China	3,886,000	SAS in Transition
70	Frankfurt	Germany	3,712,000	MAS
75	Melbourne	Australia	3,577,000	MAS
77	Montreal	Canada	3,470,000	SAS in Transition
83	Berlin	Germany	3,327,000	MAS
84	Dusseldorf	Germany	3,301,000	MAS
85	San Francisco	United States	3,300,000	MAS
97	Johannesburg	South Africa	3,084,000	SAS in Transition
105	Tel Aviv	Israel	2,917,000	MAS
112	San Diego	United States	2,765,908	MAS
117	Stuttgart	Germany	2,697,000	MAS
118	Bologna	Italy	2,690,000	MAS
119	Hamburg	Germany	2,681,000	MAS
121	Rome	Italy	2,664,000	MAS
127	Nairobi	Kenya	2,574,000	SAS in Transition
130	Taipei	Taiwan	2,505,000	MAS
135	Venice	Italy	2,474,000	MAS
146	Glasgow	United Kingdom	2,300,000	MAS
152	Manchester	United Kingdom	2,202,000	MAS
153	Warsaw	Poland	2,199,000	SAS in Transition
155	Vienna	Austria	2,178,000	MAS
157	Tampa	United States	2,168,000	MAS
169	Vancouver	Canada	2,059,000	MAS
174	Brussels	Belgium	1,975,000	MAS
175	Lisbon	Portugal	1,962,000	SAS in Transition
187	Cleveland	United States	1,813,683	MAS
211	Stockholm	Sweden	1,696,000	MAS
227	Norfolk	United States	1,569,000	MAS
267	Cochin	India	1,412,000	SAS in Transition
286	Kuala Lumpur	Malaysia	1,352,000	SAS in Transition
293	Pisa	Italy	1,327,000	MAS
295	Hyderabad	India	1,319,000	SAS in Transition
314	Orlando	United States	1,244,000	MAS
351	Amsterdam	Netherlands	1,144,000	MAS
364	Auckland	New Zealand	1,117,000	SAS in Transition
387	Copenhagen	Denmark	1,066,000	MAS
	Edmonton*	Canada	990,000	SAS in Transition
	Oslo*	Norway	839,000	MAS
	Gothenburg*	Sweden	788,000	MAS
	Belfast*	United Kingdom	579,000	MAS
	Leipzig*	Germany	508,000	SAS in Transition

Despite the fact that the 27 metropolitan regions (of the 60 largest) worldwide that have not yet transitioned to multi-airport systems (Table 26) currently exhibit significant population basin, the economic drivers of demand for air transportation (i.e. GDP) are not evolving at the same rate, nor the residents in the regions have the same purchasing power. In order to refine the analysis of future demand for traffic, an analysis of the characteristics and evolution of socio-economic factors was performed. Figure 96 shows, for each of the metropolitan region with a population greater than 1 million, the rate of growth of GDP per capita (average annual rate of growth between 2000 and 2007) versus GDP per capita of the countries of location of these metropolitan regions[1]. The size of the circle is proportional to the population in the metropolitan region.

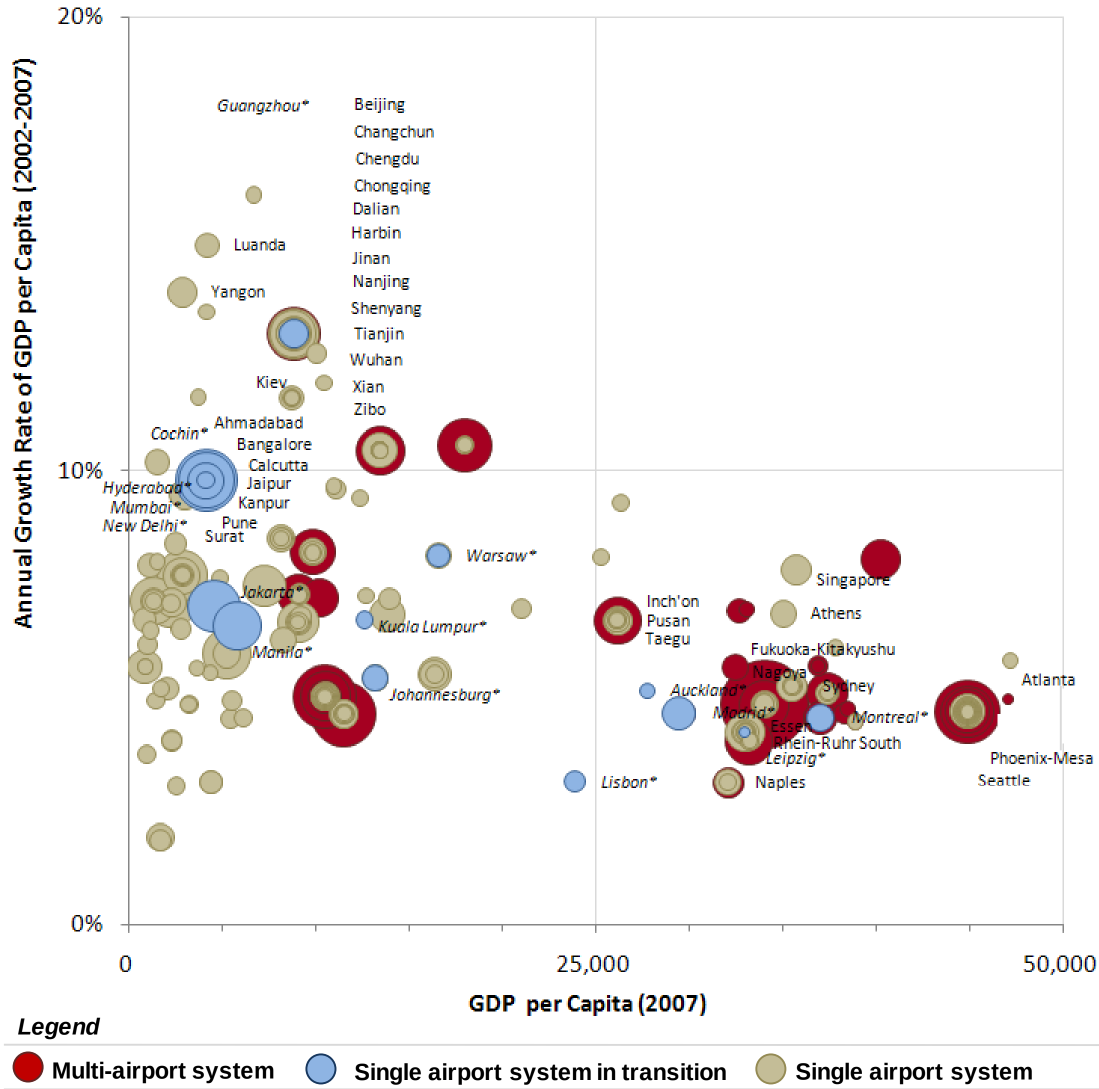

Figure 96: Annual Growth Rate of GDP per Capita (2002-2007) versus GDP per Capita (2007) for metropolitan regions with multi-airport systems, single airport systems in transition and single airport systems[2]

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[1] Note: Due to the lack of availability of detailed data on Gross Regional Product by metropolitan regions, GDP was used as a proxy for GRP.

[2] Data sources: (1) GDP per Capita and CAGR of GDP per Capita; Euro monitor database, MIT license, (2) Population data: United Nations (UN), Demographic Yearbook, Table 8; Population of capital cities and

Figure 96[1] shows three categories of metropolitan regions that exhibit different dynamics. Metropolitan regions in the lower right quadrant of Figure 96 are located in countries that have medium to high GDP per capita but are growing at a slow rate. The metropolitan regions that tend to grow at slow rates in developed countries and likely to exhibit barriers to the construction of new high capacity airports are more likely to transition to multi-airport systems through the emergence of secondary airports. Metropolitan regions in the upper left quadrant of Figure 96, are regions that have low to medium GDP per capita but are growing at a rapid rates. In these regions, the development of airport systems is likely to be initiated by passenger traffic forecast based on high annual rate of growth (cf. Feedback model, section 6.4.2). In the regions where the set of usable existing airports is small, the process of planning and construction of new airport is likely to be triggered. A significant number of these metropolitan regions are located in China where a significant effort to build new airports is underway. In fact, in its airport development plan (from 2008 to 2020), the General Administration of Civil Aviation of China (CAAC) plans to build 97 new airports nationwide[2] (China Daily, 2008). In 2007, there were 486 airports in China (i.e. all runway size, and pavement type) (CIA, 2007), of which 321 had paved runways longer than 5,000 ft. The 12 year development plan was based on a forecast of 11.4% annual growth of traffic until 2020 (China Daily, 2008).

Figure 97 shows the annual growth rate of GDP per Capita versus the estimated gross regional product in 2007 for 420 metropolitan regions worldwide.

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cities of 100,000 and more inhabitants: latest available year, available at: http://unstats.un.org/unsd/demographic/sconcerns/densurb/densurb2.htm#City, last accessed; February 2008.

[1] Data source: GDP per Capita and CAGR of GDP per Capita data from Central Intelligence Agency, The World Wide Fact Book, 2006, available at: https://www.cia.gov/library/publications/the-world-factbook/index.html, last accessed: December 2007.

[2] Note: The distribution of airports across China is expected to be; 24 in the North and Northeast, 12 in East China, 14 in South and Central China, 21 in Southwest China, and 26 in Northwest China.

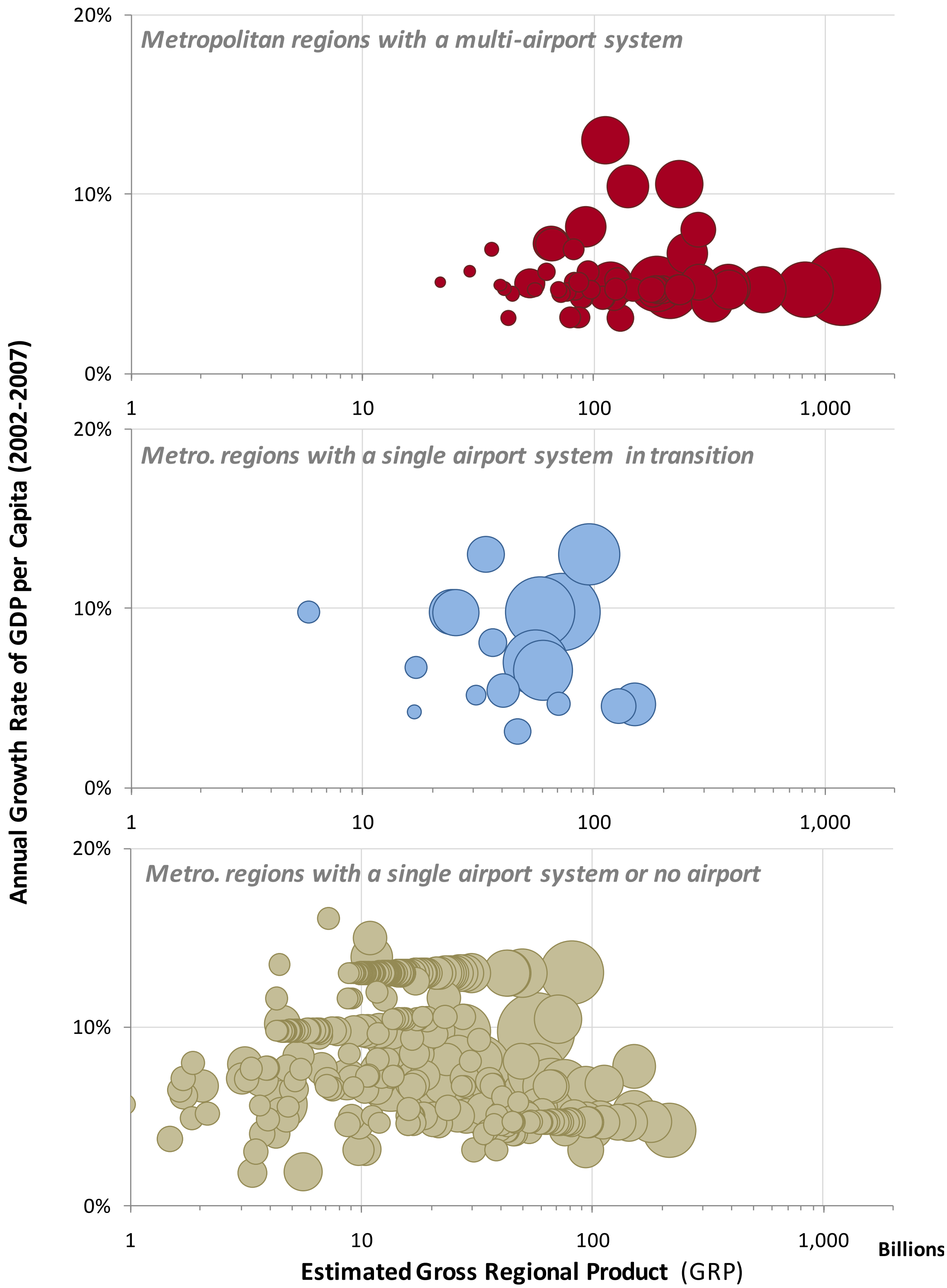

Figure 97: Annual Growth Rate of GDP per Capita (2002-2007) versus Estimated GRP (2007) for 420 metropolitan regions worldwide

9.3 Implications of Worldwide Trends in the Development of Low-Cost Carriers

Low-cost carriers historically emerged in the United States and then in Europe. However, their development is not limited to these two world regions. Figure 98 shows, as of 2007, the distribution of low-cost carriers worldwide with their year of creation. Figure 98 shows that the birth and death of low-cost carriers occur by wave in different regions of the world. The United States and Canada are mature markets for low-cost carriers, with a significant number of defunct carriers and a limited emergence of carriers in the recent years. Europe is in transition with already defunct carriers and significant number of low-cost carriers that emerged prior to 2004, but with also a large number that emerged since 2005. The wave of development of low-cost carriers has also started to reach other regions of the world.

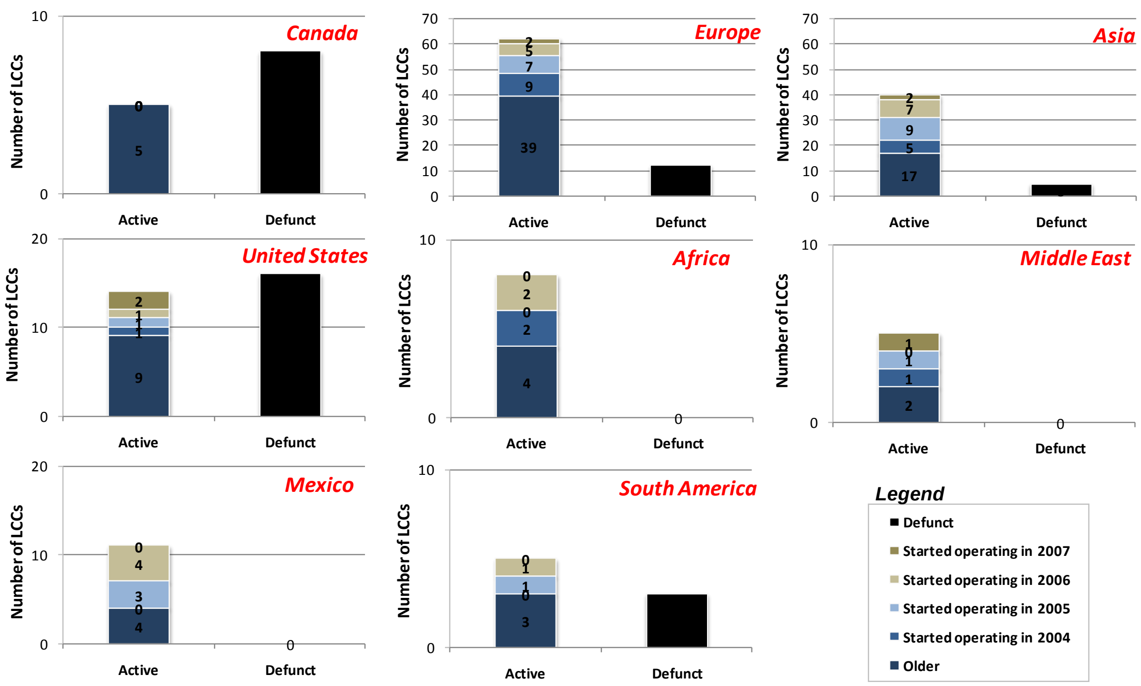

Figure 98: Distribution and evolution of low-cost carriers by world region

Some of the world regions are already showing signs of potential emergence of secondary airports (cf. Table 24). As traffic grows in these regions, the development of low-cost carriers will continue and their quest for lower cost airports is likely to result in the emergence of under-utilized airports into secondary airports where applicable (i.e. where the existing airport infrastructure will permit this dynamic to happen).

9.4 Implications for Future Airport Infrastructure Planning and Development of Multi-Airport Systems

9.4.1 Potential patterns of evolution of multi-airport systems

a. Necessary conditions for future development and proactive strategies

The lessons learned from the worldwide analysis of the dynamics of multi-airport systems imply that there are multiple solutions to their development. Multi-airport systems develop differently in different regions of the world and countries largely based on the conditions and dynamics that differ in each of them.

First, there are high level drivers and constraints that will prevail in different regions of the world more predominantly than in other regions;

- Projection of future demand of traffic with the region,
- Constraints on the ability to develop airport infrastructure,

Second, there are conditions specific to the air transportation systems in different world regions or countries that can influence the development and evolution of multi-airport systems;

- Availability of existing airports or land areas on which airports could be developed.

As a result of these drivers, constraints and conditions, several modes of evolution can be envisioned;

- For countries with high projected growth rate, lack of existing airport infrastructure to accommodate growth, the construction path is likely to be prevalent.
- For countries where constraints on the development of future airport infrastructure is or will be strong, and that have available under-utilized airports in their metropolitan regions, the evolution through emergence of secondary airports is likely to prevail.

While these scenarios would allow the future development of multi-airport systems, they are based on fundamental assumptions of necessary conditions; availability of usable land space for the future construction of new airport (i.e. in the case of the construction of new airports) and availability of existing under-utilized airports (i.e. in the case of the emergence of secondary airports). One way to meet these conditions is through the use of planning and protection mechanisms based on real option concepts (i.e. a real option is the right, but not the obligation, to undertake some business decision at a later time). This would permit the development of future multi-airport systems. Figure 99 shows conceptually how necessary conditions can be ensured through real option based strategies that permit the future downstream development of multi-airport systems either through the path of construction of new airports or the emergence of secondary airports.

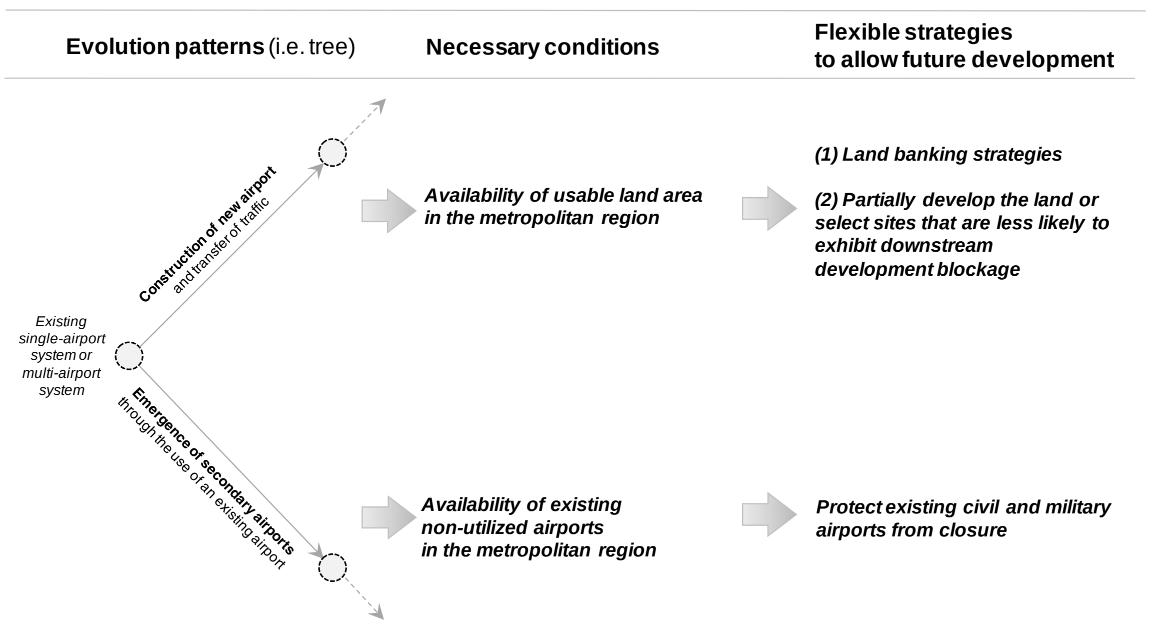

Figure 99: Use of real options to ensure feasibility of evolution paths of multi-airport systems

b. Closure of airports; lost option for future emergence

The closure of an airport and its transformation and use for non air transportation purpose forfeit the possibility of using this capacity (from an air transportation perspective) in the future.

There are two general cases to distinguish in the processes affecting the closure of airports; (1) the transfer of traffic from a primary airport to another airport in the region followed by a closure of the original airport and (2) the closure of non-utilized airports in a metropolitan region.

In the first case, the transfer of traffic to a new airport leaves an airport with limited usage and that is subject to closure. In most cases, the original airports are located closer to the center of the city than the new primary airports (cf. Section 8.2.1.b.). Despite the transfer of traffic to an external primary airport, these airports remain attractive due to their location. Their closure forfeited the opportunity to re-use them in the future.

Table 28: Cases of original primary airports that were closed after the transfer of traffic to a new airport

World Region	Airport name	History
North America	Denver/Stapleton	Denver Stapelton was the primary airport in the metropolitan region until it closed in 1995. The airport was later developed for residential and commercial use.
Europe	Oslo/Oslo Fornebu	Oslo/Fornebu was the primary airport until it ceased operations and closed in 1998. Redeveloped as a research and housing area.
Asia/Pacific	Hong Kong/Hong Kong/Kai Tak	Closed in 1998 and replaced by the new Hong Kong/Chek Lap Kok. The airport is being transformed into hotels, commercial and residential real estate.
Asia/Pacific	Guangzhou/Guangzhou Baiyun	Closed in 2004.
Europe	Gothenburg/Torslanda	Closed in 1977 when traffic was transferred to Gothenburg/Landvetter. The land has been redevelopped into residential area.

There are several cases of original airports that lost traffic due to transfer of traffic to an external primary, and then became successful secondary airports.

Table 29: Cases of original primary airports that remained opened (after loss of traffic) and then became or could become secondary airports

World Region	Airport name	History
North America	Chicago/Midway	Currently a secondary airport. It was not closed after the transfer of traffic to Chicago/O'Hare and regained traffic with carriers such as Southwest.
North America	Dallas/Love Field	Currently a secondary airport. It did not closed after the transfer of traffic to Dallas/Fort Worth. It became a key airport for Southwest.
North America	Houston/Hobby	Currently a secondary airport. It was not closed after the transfer of traffic to Houston/Intcnl and serve domestic traffic mostly by Southwest.
Asia/Pacific	Jakarta/Halim Perdanakusuma	Potential Secondary. It was the primary airport in the region until 1985. It is now used for private and business aviation.
Asia/Pacific	Auckland/Whenuapai	Potential Secondary. It may re-emerge as a secondary airport after change of status (from military status) to serve domestic traffic.
Asia/Pacific	Kuala Lumpur/Subang	Potential Secondary. Served as a primary airport until 1998. It is now used for general aviation and turboprop domestic flights.

The closure of non-utilized airports in a metropolitan region also forfeits any opportunity to re-use them in the future for meeting demand in the metropolitan region. The case of Boston/South Weymouth (Naval Air Station) that was a former military airfield located south of Boston illustrates this. Boston/South Weymouth is under redevelopment into shops, housing, a wildlife park and a golf course.

9.4.2 Implications for the future development of multi-airport systems in different world regions

In *North America* and in *Europe*, the constraints on expanding the capacity of existing primary airports implies the need to protect existing under-utilized airports that will be key to meeting future demand. These constraints arise from inherent land use issues (i.e. inability to physically expand the footprint of the airports) and opposition from local communities to expand airports using environmental impact justifications. These constraints coupled with the findings of the analysis of the available airport infrastructure imply that existing under-utilized airports will be key to accommodating future demand. However, weak streams of revenue due to low passenger traffic and competition for land use (i.e. transformation of under-utilized airports into real estate or industrial development) could threaten the continuing existence of under-utilized airports. These existing airports should be seen as options for future development and for future accommodation of air transportation demand.

In parts of *Asia-Pacific* where the existing under-utilized airport infrastructure is weak and where projections of volume of demand are large[1] (i.e. *China*), there is the need to apply a real option based approach to develop multi-airport systems through the construction of new airports. This approach includes actions such as reserving land area for future airport development and keeping original airports open since this option has proven to be useful and successful in the United States. In addition, in parts of *Asia-Pacific* such as *India* where the military airport infrastructure is more developed, there is also the need, as in the United States and Europe, to protect these airports since they may become future secondary airports following the airport status conversion dynamics that were observed in Europe.

[1] Note: The projections of future traffic are not only high but also exhibit significant uncertainty.

9.5 Implications for Air Traffic Control (ATC) and Next Generation Air Transportation Systems

The transition from single airport systems to multi-airport systems with primary and secondary airports closely located from each other results in the emergence of air traffic pattern interactions between airports. The arrival and departure paths to and from airports interact and limit the capacity of the multi-airport system. As a result, the capacity of the combined airports is lower than in the case for which the airports would be operated independently. Figure 100 shows the approach and departure paths to and from three primary airports (i.e. New York/LaGuardia, New York/Kennedy and New York/Newark) and one high density general aviation airport (i.e. New York/Teterboro) in the New York region.

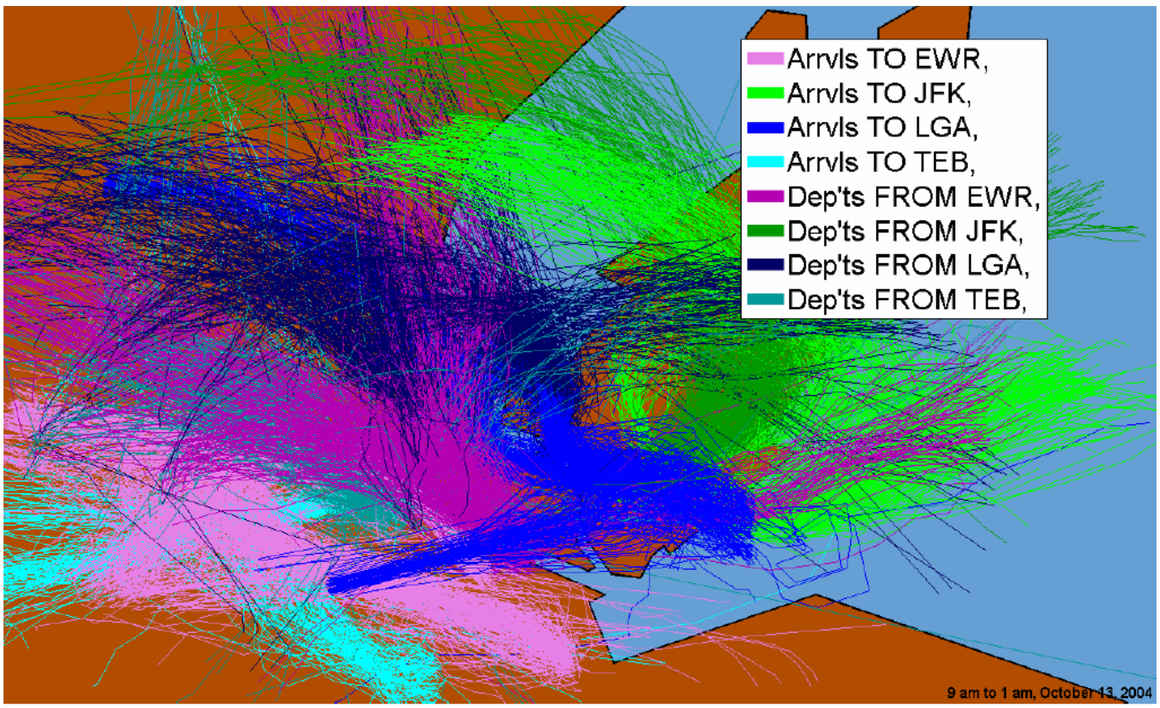

Figure 100: Air traffic patterns in the New York region (courtesy of Jonathan Histon, MIT ICAT)

The New York multi-airport system illustrates these interacting effects between individual airports. For instance, operations at New York/Teterboro are strongly affected when New York/LaGuardia is operated under ILS 13 configurations and New York/Newark in ILS 22L configurations for arrivals. Similarly, ILS 6 at Teterboro also conflicts with ILS 11 at New York/Newark (Figure 101).

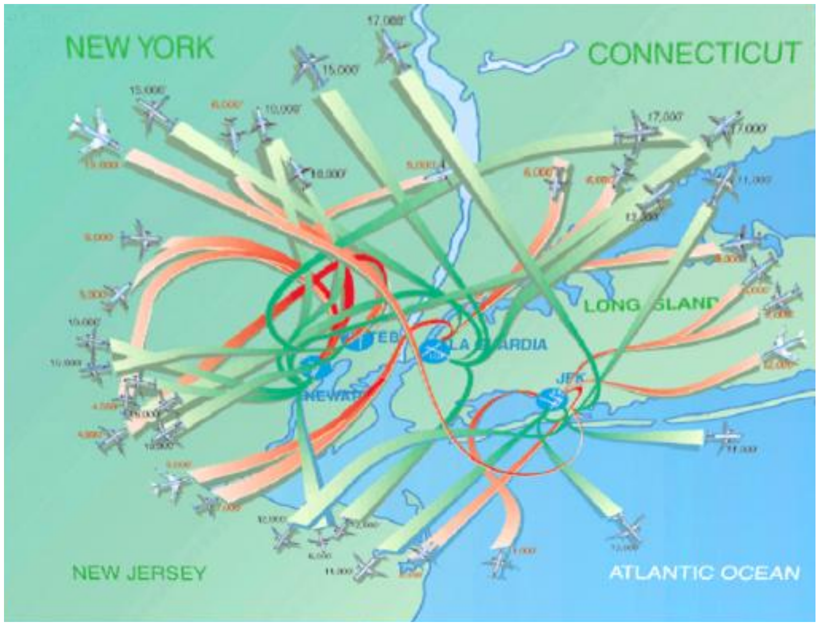

Figure 101: Approach and departure paths for the New York multi-airport system [Source: New York airspace redesign project (FAA, 2006)]

In order to assess the total capacity of multi-airport systems, an analysis of the Pareto frontiers of the traffic inflow and outflow was performed. Data from the Enhanced Traffic Management System (ETMS) for April 2006 was used. The analysis included New York/LaGuardia (LGA), New York/Newark (EWR), New York/Kennedy (JFK), New York/Islip (ISP) and New York/Teterboro (TEB). Multi-airport system capacity plots were constructed. The concept of multi-airport system capacity plots is an extension of the concept of airport system capacity plots.

An airport system capacity plot is constructed using hourly arrival and departure rates over a defined time window of observation (e.g. time during which a certain airport configuration is used). The observed capacity of the airport system is given by the Pareto frontier which is the convex set of arrival and departure counts (i.e. points). This capacity represents the maximum throughput of the airport during the defined time window of observation. This data based capacity is generally different from the theoretical capacity of the airport. For heavily utilized airports (i.e. especially those that exhibit delays which is an indication that they are operated close to their maximum capacity), the capacity computed from data based capacity is generally close to the theoretical capacity of the airport. The extension of the concept airport system capacity plot to multi-airport system capacity plots is simply a change in the definition of the control volume, from the airspace around an individual airport to the airspace surrounding a set of airports located close to each other. Figure 102 shows the multi-airport system capacity plot for the New York region. The data points (i.e. combinations of arrival and departure rates) were broken down by time of day. As shown on Figure 102, during the early morning (i.e. from 06:00 to 10:00) operations in the New York multi-airport system are composed predominantly by departures. These correspond mostly to large numbers of east-west domestic flights. The balance between arrivals and departure is reached between 10:00 to 14:00. Peaks of departure and arrival rates, that define the Pareto frontier, are reached between 14:00 and 18:00.

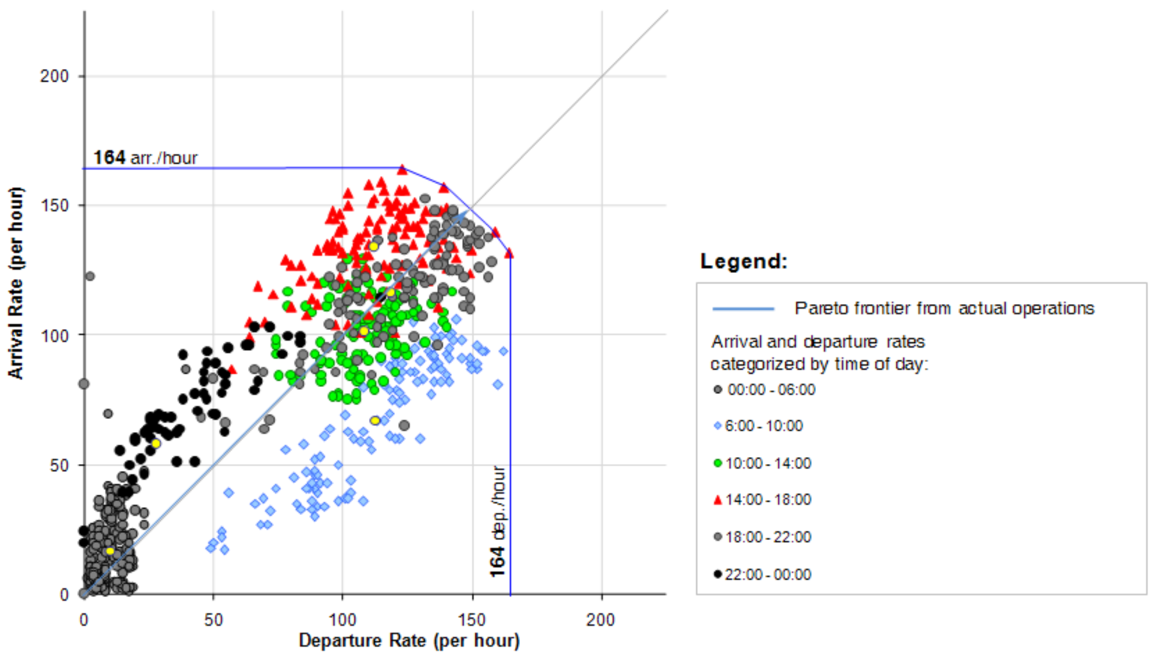

Figure 102: Multi-airport system capacity plots with Pareto frontiers for the New York system

The interactions between airports that are part of the multi-airport system limit the departure and arrival rates to values that are lower than what they would be if airport operations were decoupled.

Implications for air traffic control

The implications of the interactions between airports and the limited ability to add airport capacity in some multi-airport systems suggests that there is the need to reduce these interactions by developing air traffic management paradigms and tools that would alleviate these interactions. Super Density Operations (SDO) concepts address these interactions. These concepts are largely based on simultaneous sequencing, spacing, merging, and de-confliction for operations within the terminal airspace.

Implications of air traffic control considerations for the development of future multi-airport systems

The interactions between air traffic flows identified in the New York multi-airport system are largely due to the geographical configuration of airports and runways at these airports. This configuration is the result of legacy elements of the system (i.e. selection of sites and construction of airports at a time where air traffic operations were different and the density of traffic was lower). Recognizing that as the number of airports in a multi-airport system increases, interactions and coupling between air traffic flows can limit the capacity of the system, the layout and the construction of second, third, fourth, etc. airports in a metropolitan region should take into account these potential interactions. This is especially true in Asia-Pacific where it was shown that multi-airport systems tend to evolve predominantly through the construction of new airports. From the start, the design and layout of the runways and the airport can reduce the interactions with other airports in the metropolitan region and avoid the emergence of these interactions as the density of traffic in these multi-airport systems increases.

CHAPTER 10

CONCLUSIONS & CONTRIBUTIONS

This section presents first the conclusions of this research and study, starting with network analysis and the insights derived from it. The conclusions from the multiple-case study analysis of multi-airport system are presented and followed by those on the potential future evolution of the multi-airport systems. The implications of these findings on how to better plan, operate and manage these systems are then presented.

Finally, the contributions of this research to the air transportation system domain and to Engineering Systems are presented.

10.1 Conclusions

10.1.1 Network analysis

The analysis of the structure of the U.S. air transportation network showed that the U.S. air transportation network is not scalable at the airport level due to capacity constraints. These limit the growth of the nodes and as a consequence influence the evolution of the overall structure of the network. In contrast, the analysis of the U.S. air transportation network for which multiple airports serving the same metropolitan region were aggregated into multi-airport system nodes showed that the network was scale-free and scalable.

The temporal analysis of the evolution (i.e. growth of nodes in the network versus their weight in the network) also showed that when airports within multi-airport systems were aggregated into single nodes the deviation from the preferential attachment model was reduced. While most of the aggregated multi-airport system nodes followed the linear relationship (i.e. were growing according to preferential attachment dynamics), a deviation from the linear relationship was found for the largest of these nodes (i.e. New York). It is believed that the lower growth rate of the New York multi-airport system node is due in part to regional level constraints such as airspace capacity limits.

These analyses showed that regional level scaling mechanisms (i.e. development of multi-airport systems) was a key mechanism by which the air transportation system scaled and met future demand in the past.

10.1.2 Dynamics influencing the evolution of multi-airport systems

Given the findings from the network analysis that showed the importance of the development of multi-airport systems, a detailed analysis of the dynamics that govern these systems was performed. A multiple-case study analysis of 59 multi-airport systems worldwide formed the basis for the development of a feedback model. This model captured the processes (i.e. causal relationships and feedback loops) that govern the evolution of these systems.

Based on the multiple-case study analysis, it was found that multi-airport systems evolve according to two fundamental mechanisms; (1) the construction of new airports and transfer of traffic and (2) the emergence of existing non-utilized airports (that result in secondary airports). Several differences and similarities across world regions were identified. In the United States and Europe, the construction of new airports generally occurred prior to or during World War II. During the last decades, significant limitations to the development of new airports (i.e. opposition from local communities using environmental impact reasons) limited the development of these airports. As a result of these constraints and changes in the airline industry (i.e. emergence and growth of low-cost carriers), multi-airport systems in the United States and Europe have evolved predominantly through the emergence of secondary airports though the utilization of existing airports. In Europe, this trend of secondary airport emergence was predominant and more recent in than in the United States (i.e. due to the emergence and growth of low-cost carriers after deregulation in the early 1990s). In Asia-Pacific, multi-airport systems have generally evolved through the construction of new airports, due to a much weaker set of available airports, high perceived benefits of strong growth of traffic and weaker opposition to the construction of new airports.

10.1.3 Future evolution of multi-airport systems

This study and the framework that was developed for analyzing the evolution of multi-airport systems can be helpful for understanding the future evolution of these systems and guiding future policy decisions.

The worldwide analysis of the dynamics of multi-airport systems showed that multi-airport systems develop differently in different regions of the world and countries largely based on the conditions and dynamics that differ between world regions. Differences are expected to remain. This also suggests that there is no single way of developing multi-airport systems but rather an array of paths and strategies. Different drivers (e.g. projection of future demand of traffic), constraints (e.g. opposition from local communities) and conditions of the air transportation systems (e.g. availability of existing airports or land areas on which airport could be developed) will prevail in the future. As a result, for countries with high projected growth rate and lacking existing airport infrastructure to accommodate growth, the construction path is likely to be prevalent. For countries where constraints on the development of future airport infrastructure is or will be strong, and that have available under-utilized airports in their metropolitan regions, the evolution through emergence of secondary airports is likely to prevail.

This research also showed the need to apply a real option based approaches to enable the future development of multi-airport systems by; (1) protecting existing airport infrastructure (both civil and military airports) in region that face constraints of the development of new airports and (2) apply land banking strategies in regions where the existing under-utilized airport infrastructure is weak and where projections of high volume of demand.

This means that in North America and in Europe, given the constraints on expanding the capacity of existing primary airports there is the need to protect existing under-utilized airports that will be key to meeting future demand. In parts of Asia-Pacific where the existing under-utilized airport infrastructure is weak and where projections of volume of demand are large[1] (i.e. China), there is the need to apply a real option based approach to develop multi-airport systems through the construction of new airports. This approach

[1] Note: The projections of future traffic are not only high but also exhibit significant uncertainty.

includes actions such as reserving land area for future airport development and keeping original airports open since this option has proven to be useful and successful in the United States. In addition, in parts of Asia-Pacific such as India where the military airport infrastructure is more developed, there is also the need, as in the United States and Europe, to protect these airports since they may become future secondary airports following the airport status conversion dynamics that were observed in Europe.

10.1.4 Multi-airport systems and Air Traffic Control

Both the network analysis (i.e. time series analysis) and the analysis of the implications of the development of multi-airport systems showed that the emergence of regional level constraints and limit to growth. Operational interactions between airports were identified as a factor that limits the capacity of a multi-airport system. This suggests that there is the need to develop air traffic control solutions to (1) reduce these interactions and (2) increase the capacity of these systems. Super Density Operations (SDO) concepts (i.e. based on simultaneous sequencing, spacing, merging, and de-confliction for operations within the terminal airspace) address the effects of these interactions.

10.2 Contributions

The development of a multi-level approach for the analysis of a large scale complex engineering system (i.e. air transportation system) proved to be insightful.

First, this approach showed that the property of the system (i.e. scalability) could be evaluated at the highest level of observation of the system (i.e. national and international levels). For this purpose, network theory was used in a novel way to show the importance of multi-airport systems in the scalability of the air transportation system. It was demonstrated that the US air transportation network is not scale-free at the airport level. By using a multiple case studies of multi-airport systems and analyzing the system at the regional level, by aggregating multiple nodes into mega nodes, scale-free properties of the networks were identified.

Second, the multi-level approach showed how deeper understanding of the dynamics of sub-components of the system (i.e. multi-airport systems and airport systems) influenced the evolution of the system. For this analysis, a feedback model of the dynamics influencing the evolution of multi-airport systems was developed based on an in-depth analysis of a set of 59 cases of existing multi-airport systems. The framework that was used to analyze multi-airport systems (e.g. methodology for identifying and analyzing multi-airport systems, formalism for analyzing the ownership and management forms of airports, etc.) and the feedback model can be used to analyze and better understand the evolution of future multi-airport systems.

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APPENDIX

Appendix A: Network Analysis

Appendix A-1: Computation of correction factors for network degree distributions with finite maximum degree

Because the distribution of degrees has a finite upper limit and way the power law is constructed, the deviation from the power law fit (i.e. straight line) is slightly greater than it would be for a distribution of non-finite flight weighted range. In order to verify the validity of the observation of a non-power law part in the distribution, a method of correction of distribution of degrees with finite upper limits was developed. This iterative method applies a correction equal to the integral of the power law function from the finite upper limit of flight weighted degree to infinity.

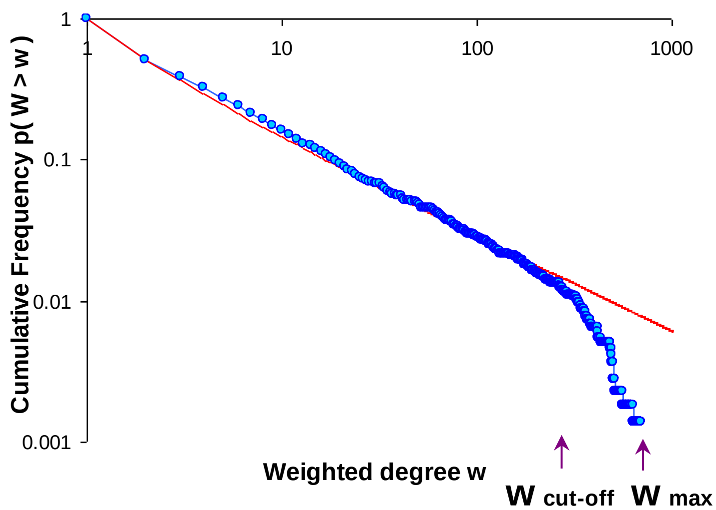

Figure 103: Degree distributions with finite maximum degree

Figure 103 shows the illustration of a weighted degree distribution with a finite limit (i.e. w_{max}). Figure 104 shows the iterative process of correction of the degree distributions.

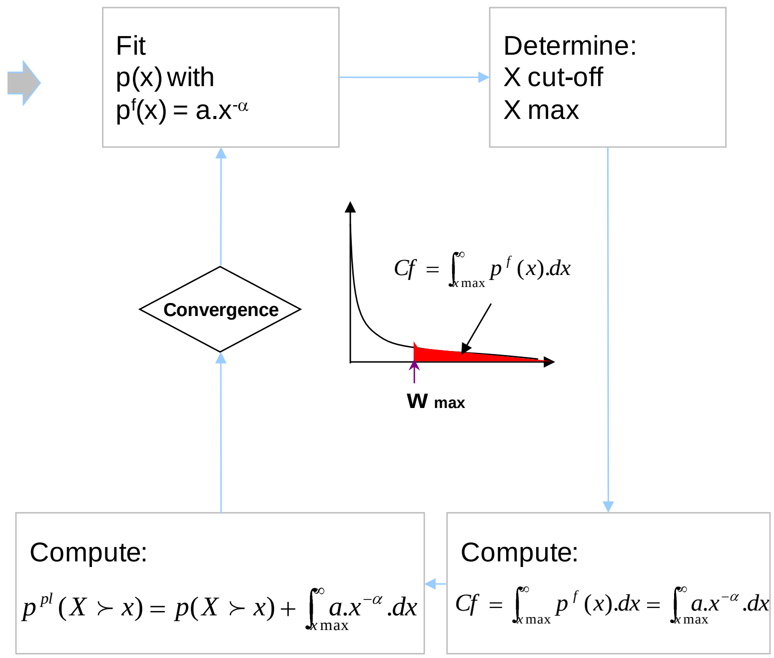

Figure 104: Iterative process for identifying non-scale-free distributions with finite maximum degree

The results of the correction method are presented in Figure 105.

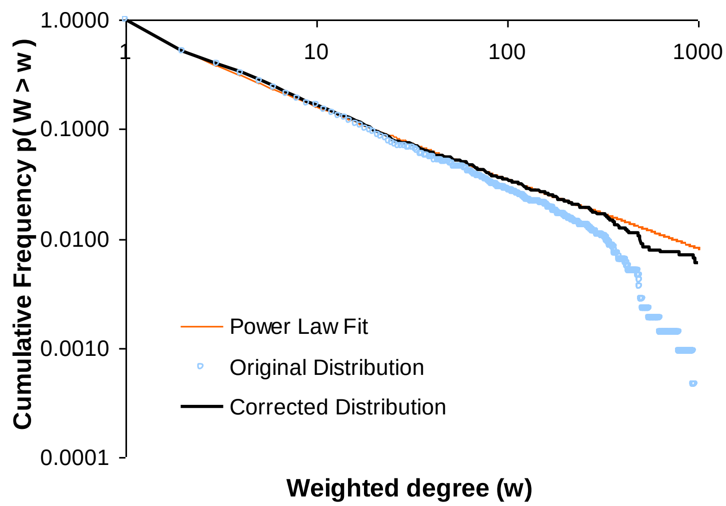

Figure 105: Degree distributions with finite maximum degree (with and without correction applied)

Appendix A-2: Analysis of parallel air transportation networks in the United States

From a network perspective, the emergence of a new primary and secondary airports in a metropolitan region results in the creation of new connections to the rest of the airport network. The emergence of Boston/Providence as part of the Boston multi-airport system has created of new origin-destination (OD) pairs such as Boston/Providence (PVD) to Chicago/O'Hare (ORD), which is a secondary to primary airport market, and Boston/Providence (PVD) to Chicago/Midway (MDW) which is a secondary-to-secondary airport market. These routes parallel the primary-to-primary airport route; Boston/Logan (BOS) to Chicago/O'Hare (ORD).

Figure 106 shows the structure of the networks of flights from primary-to-primary airports, and the networks of flights from primary-to-secondary and secondary-to-secondary airports, based on ETMS data for the time period from October 1st 2004 to September 30th 2005.

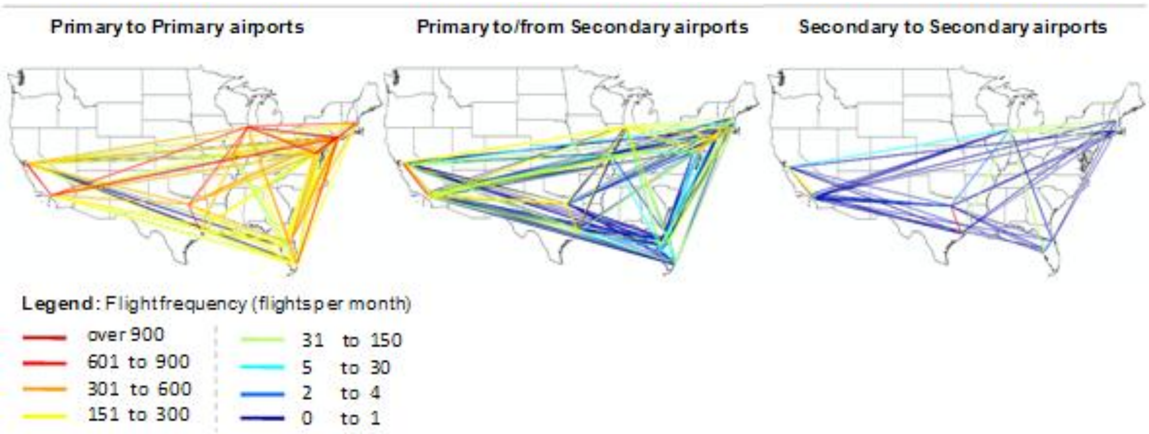

Figure 106: Parallel and semi-parallel networks in the U.S. air transportation network

Using BTS Form 41 traffic data[1] for the months of March 1990 and 2003, capturing respectively a total of 18,000 and 15,000 distinct origin-destination (OD) pairs, the number of OD pairs for each category was computed for both periods. It was found that semi-parallel networks (i.e. primary to secondary airport network) grew by 13 % in terms of number of routes served, from 439 to 193 connections. The largest growth was observed in the parallel network category (i.e. secondary to secondary airport network)

[1] Data source: Bureau of Transportation Statistics, Aviation, Airline Origin and Destination Survey DB1B, available at: http://www.transtats.bts.gov/, last accessed; Feb. 2005.

where the network grew by 49%. This phenomenon resulted from the emergence and growth of secondary airports in the 1990s (e.g. Boston/Providence, Boston/Manchester, etc). The introduction of new OD pairs between secondary to secondary airports is the result of the strategy of carriers like Southwest that operate largely at secondary airports and connect them together with point-to-point flights.

Appendix A-3: Time series analysis at airports and multi-airport systems in the United States from 1976 to 2005

In order to assess the relative annual growth of nodes versus their relative size in the network, an extension to the historical analysis was conducted (cf. Chapter 5). The analysis presented in Chapter 5 used commercial operations (Figure 108). Using data from historical records from the Terminal Area Forecasts, an additional analysis was performed for passenger enplanements and total operations.

<u>Time series analysis of passenger enplanements</u>

Similarly to the findings from the analysis of commercial operations, the results of the analysis of passenger traffic at the airport level show a deviation from the linear growth model (i.e. preferential attachment model). Lower deviation was observed in the case where multi-airport systems are aggregated into single nodes.

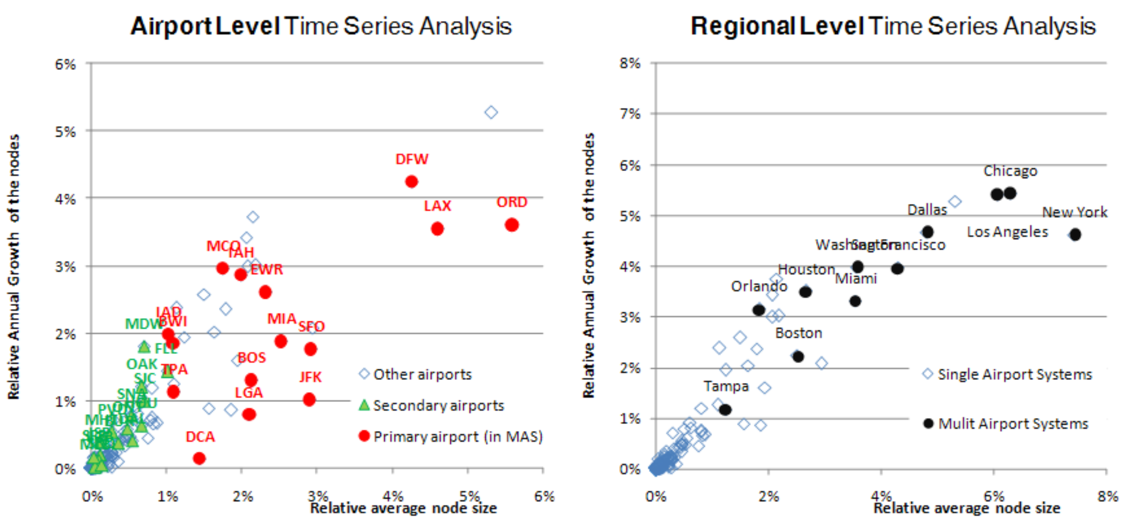

Figure 107: Relative annual growth versus relative size based on passenger enplanement data for airports and multi-airport systems in the United States from 1976 to 2005

<u>Time series analysis of total operations (i.e. air carrier, air taxi and general aviation)</u>

The analysis was also extended to a data set composed of all operations performed at all airports covered by the FAA Terminal Area Forecast database. Similarly to the findings from the analysis of commercial operations and passenger enplanements, the results of the analysis of total operations also showed lower deviation in the case where multi-airport systems are aggregated into single nodes. Overall the deviation from the linear model is higher with the dataset composed of total operations due to the large volatility of general aviation traffic that is embedded in this dataset.

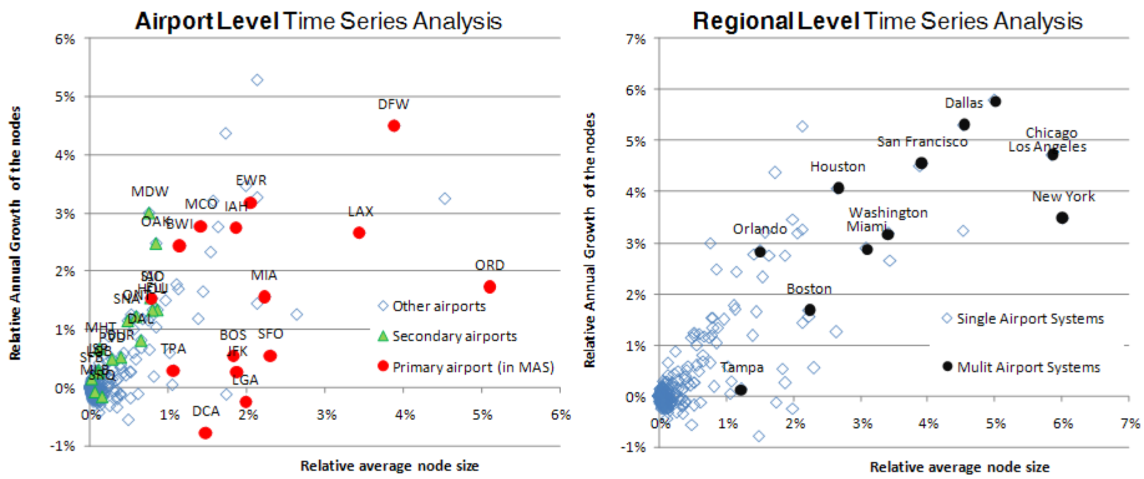

Figure 108: Relative annual growth versus relative size based on total operation data for airports and multi-airport systems in the United States from 1976 to 2005

Appendix B: Multiple-Case Study Analysis; Supporting Material

Appendix B-1: Airport codes and names

IATA code	ICAO code	Airport Name (Used for the purpose of this research)	Other Names (Used in the literature)	
EIN	EHEH	Amsterdam/Eindhoven	Eindhoven	
RTM	EHRD	Amsterdam/Rotterdam	Rotterdam	Rotterdam Zestienhoven
AMS	EHAM	Amsterdam/Schiphol	Amsterdam Schiphol	Schiphol
AKL	NZAA	Auckland/Intl	Auckland Intl	
	NZWP	Auckland/Whenuapai		
DMK	VTBD	Bangkok/Don Mueang	Bangkok Don Muang Intl	Bangkok Intl
BKK	VTBS	Bangkok/Suvarnabhumi	Bangkok Suvarnabhumi	
GRO	LEGE	Barcelona/Gerona	Gerona Costa Brava	
BCN	LEBL	Barcelona/Intl	Barcelona	Barcelona
REU	LERS	Barcelona/Reus	Reus	
BHD	EGAC	Belfast/City	Belfast City Airport	
BFS	EGAA	Belfast/Intl	Belfast Intl/Aldergrove	Aldergrove
CNF	SBCF	Belo Horizonte/Neves	Belo Horizonte Tancredo Neves	Tancredo Neves Intl
PLU	SBBH	Belo Horizonte/Pampulha	Belo Horizonte Pampulha	
EDAV*	EDAV	Berlin/Eberswalde-Finow	Eberswalde-Finow	Finow
SXF	EDDB	Berlin/Schoenefeld	Berlin Schoenefeld	Schonefeld
TXL	EDDT	Berlin/Tegel	Berlin Tegel	Tegel
THF	EDDI	Berlin/Tempelhof	Berlin Tempelhof	Tempelhof
FRL	LIPK	Bologna/Forli	Forli	
BLQ	LIPE	Bologna/Intl	Bologna	Bologna Borgo Panigale
BOS	KBOS	Boston/Logan	General Edward Lawrence Logan Intl	
MHT	KMHT	Boston/Manchester	Manchester	
PVD	KPVD	Boston/Providence	Providence Theodore Francis	Theodore Francis Green State
CRL	EBCI	Brussels/South Charleroi	Brussels South Charleroi	Brussels South
BRU	EBBR	Brussels/Zaventem	Brussels Natl	
AEP	SABE	Buenos Aires/Newbery	Buenos Aires J. Newberry Intl	Aeroparque Jorge Newbery
EZE	SAEZ	Buenos Aires/Pistarini	Buenos Aires Ministro Pistarini	Ministro Pistarini
MDW	KMDW	Chicago/Midway	Chicago Midway	Chicago Midway Intl
ORD	KORD	Chicago/O'Hare	Chicago O'Hare	Chicago Ohare Intl
CAK	KCAK	Cleveland/Akron-Canton	Akron-Canton	
CLE	KCLE	Cleveland/Hopkins	Cleveland Hopkins International	
COK	VOCI	Cochin/Intl	Cochin Intl	
CPH	EKCH	Copenhagen/Kastrup	Copenhagen Kastrup	Kastrup
MMX	ESMS	Copenhagen/Malmo	Malmo	Sturup
DFW	KDFW	Dallas/Fort Worth	Dallas-Fort Worth Intl	
DAL	KDAL	Dallas/Love Field	Dallas Love Field	

IATA code	ICAO code	**Airport Name** (Used for the purpose of this research)	**Other Names** (Used in the literature)	
DEN	KDEN	Denver/Intl	Denver Intl	
DVX	KDVX	Denver/Stapleton	Denver Stapleton Intl	
FNT	KFNT	Detroit/Bishop	Bishop International	
DTW	KDTW	Detroit/Metropolitan	Detroit Metropolitan Wayne County	
DXB	OMDB	Dubai/Intl	Dubai Intl	
SHJ	OMSJ	Dubai/Sharjah	Sharjah Intl	
CGN	EDDK	Dusseldorf/Cologne Bonn	Cologne Bonn	Koln Bonn
DTM	EDLW	Dusseldorf/Dortmund	Dortmund	Dortmund Wickede
DUS	EDDL	Dusseldorf/Intl	Dusseldorf	Duesseldorf Rhein-Ruhr
NRN	EDLV	Dusseldorf/Weeze Niederrhein	Weeze Niederrhein	Niederrhein
HHN	EDFH	Frankfurt/Hahn	Frankfurt Hahn	
FRA	EDDF	Frankfurt/Main	Frankfurt Main	Frankfurt Rhein Main
EDI	EGPH	Glasgow/Edinburgh	Edinburgh	Edinburgh Turnhouse
GLA	EGPF	Glasgow/Intl	Glasgow Intl	Glasgow
PIK	EGPK	Glasgow/Prestwick	Prestwick	
GSE	ESGP	Gothenburg/City	Gothenburg Saeve	Save
GOT	ESGG	Gothenburg/Landvetter	Gothenborg Landvetter	Landvetter
		Gothenburg/Torslanda	Torslanda	
CAN	ZGGG	Guangzhou/Baiyun	Guangzhou Baiyun	Baiyun Intl
HAM	EDDH	Hamburg/Fuhlsbuettel	Hamburg Fuhlsbuettel	Hamburg
LBC	EDHL	Hamburg/Lubeck	Lubeck Blankensee	
HKG	VHHH	Hong Kong/Intl	Hong Kong Intl	
VIII*	VIII	Hong Kong/Kai Tak	Hong Kong Kai Tak	
SZX	ZGSZ	Hong Kong/Shenzen	Shenzen Baoan Intl	Baoan Intl
HOU	KHOU	Houston/Hobby	Houston William P. Hobby	William P Hobby
IAH	KIAH	Houston/Intercontinental	Houston Intercontinental	George Bush Intcntl Houston
	VOHS	Hyderabad/Begumpet	Begumpet	
HYD	VOHY	Hyderabad/Intl	Hyderabad	
IST	LTBA	Istanbul/Atatuerk	Istanbul Atatuerk Intl	Ataturk
SAW	LTFJ	Istanbul/Sabiha Gokcen	Sabiha Gokcen	
HLP	WIHH	Jakarta/Halim Perdanakusuma	Jakarta Halim Perdana Kusuma	
CGK	WIII	Jakarta/Soekarno Hatta	Jakarta Soekarno Hatta Intl	Soekarno Hatta Intl
JNB	FAJS	Johannesburg/Intl	Johannesburg Jan Smuts Intl	Johannesburg Intl
HLA	FALA	Johannesburg/Lanseria	Johannesburg Lanseria	Lanseria
SZB	WMSA	Kuala Lumpur/Aziz Shah	Sultan Abdul Aziz Shah Intl	
KUL	WMKK	Kuala Lumpur/Subang	Kuala Lumpur Subang Intl	Kuala Lumpur Intl
AOC	EDAC	Leipzig/Altenburg Nobitz	Altenburg Nobitz	
LEJ	EDDP	Leipzig/Halle	Leipzig Halle	
LIS	LPPT	Lisbon/Lisboa	Lisboa	Lisbon Portela De Sacavem
LCY	EGLC	London/City	London City	City
LGW	EGKK	London/Gatwick	London Gatwick	Gatwick
LHR	EGLL	London/Heathrow	London Heathrow	Heathrow

IATA code	ICAO code	**Airport Name** (Used for the purpose of this research)	**Other Names** (Used in the literature)	
LTN	EGGW	London/Luton	London Luton	Luton
STN	EGSS	London/Stansted	London Stansted	Stansted
BUR	KBUR	Los Angeles/Burbank	Burbank Pasadena	Bob Hope
LAX	KLAX	Los Angeles/Intl	Los Angeles Intl	
LGB	KLGB	Los Angeles/Long Beach	Long Beach Daugherty Field	Long Beach
ONT	KONT	Los Angeles/Ontario	Ontario Intl	
SNA	KSNA	Los Angeles/Santa Ana	Santa Ana John Wayne Intl	John Wayne Arpt Orange Co
MAD	LEMD	Madrid/Barajas	Madrid Barajas	Barajas
	MADQ	Madrid/Don Quijote	Don Quijote	
BLK	EGNH	Manchester/Blackpool	Blackpool	Blackpool Squire's Gate
MAN	EGCC	Manchester/Intl	Manchester Intl	
LBA	EGNM	Manchester/Leeds Bradford	Leeds Bradford	
LPL	EGGP	Manchester/Liverpool	Liverpool	Liverpool Speke
CRK	RPLC	Manila/Clark	Clark Intl	
MNL	RPLL	Manila/Intl	Manila Nioy Aquino Intl	Ninoy Aquino Intl
SFS	RPLB	Manila/Subic Bay	Subic Bay	
AVV	YMAV	Melbourne/Avalon	Avalon	
MEL	YMML	Melbourne/Tullamarine	Melbourne Tullamarine Intl	Melbourne Intl
CVJ	MMCB	Mexico City/Cuernavaca	Cuernavaca	General Mariano Matamoros
MEX	MMMX	Mexico City/Intl	Mexico City Benito Juarez	Licenciado Benito Juarez Intl
PBC	MMPB	Mexico City/Puebla	Hermanos Serdan Intl	Puebla
TLC	MMTO	Mexico City/Toluca	Licenciado Adolfo Lopez Mateos Intl	
FLL	KFLL	Miami/Fort Lauderdale	Fort Lauderdale Hollywood Intl	
MIA	KMIA	Miami/Intl	Miami Intl	
BGY	LIME	Milan/Bergamo Orio Al Serio	Bergamo Orio Al Serio	
LIN	LIML	Milan/Linate	Milan Linate	Linate
MXP	LIMC	Milan/Malpensa	Milan Malpensa	Malpensa
YMX	CYMX	Montreal/Mirabel	Montreal Mirabel Intl	
YMX	CYMX	Montreal/Mirabel	Montreal-Mirabel International	
PBG	KPMG	Montreal/Plattsburgh	Plattsburgh International	
YUL	CYUL	Montreal/Trudeau	Montreal Trudeau Intl	Montreal Dorval International
BKA	UUBB	Moscow/Bykovo	Moscow Bykovo	
DME	UUDD	Moscow/Domodedovo	Moscow Domodedovo	Domodedovo
UUMO*	UUMO	Moscow/Ostafievo	Moscow Ostafievo	
SVO	UUEE	Moscow/Sheremetyevo	Moscow Sheremetyevo	Sheremetyevo
VKO	UUWW	Moscow/Vnukovo	Moscow Vnukovo	Vnukovo
DEL	VIDP	New Delhi/Indira Ghandi	Delhi Indira Ghandi Intl	Indira Gandhi Intl
		New Delhi/Jewar		
ISP	KISP	New York/Islip	Islip Mc Arthur/Long Island	
JFK	KJFK	New York/Kennedy	New York John F. Kennedy	John F Kennedy Intl
LGA	KLGA	New York/LaGuardia	New York LaGuardia	La Guardia
EWR	KEWR	New York/Newark	Newark Liberty Intl	Newark International

IATA code	ICAO code	**Airport Name** (Used for the purpose of this research)	**Other Names** (Used in the literature)	
ORF	KORF	Norfolk/Intl	Norfolk Intl	
PHF	KPHF	Norfolk/News Williamsburg	Newport News Williamsburg Intl	Newport News Patrick Henry
MCO	KMCO	Orlando/Intl	Orlando Intl	
MLB	KMLB	Orlando/Melbourne	Melbourne Cape Kennedy Regional	Melbourne Intl
SFB	KSFB	Orlando/Sanford	Sanford Central Florida	Orlando Sanford Intl
ITM	RJOO	Osaka/Itami	Osaka Intl	
KIX	RJBB	Osaka/Kansai	Osaka Kansai Intl	Kansai International
UKB	RJBE	Osaka/Kobe	Kobe	
FBU	ENFB	Oslo/Fornebu	Oslo Fornebu	
OSL	ENGM	Oslo/Gardermoen	Oslo Lufthavn	
RYG	ENRY	Oslo/Moss Rygge	Moss Rygge	Rygge
TRF	ENTO	Oslo/Sandefjord	Sandefjord	Torp
BVA	LFOB	Paris/Beauvais	Beauvais Tille	Tille
CDG	LFPG	Paris/de Gaulle	Paris Charles de Gaulle	Charles de Gaulle
LBG	LFPB	Paris/Le Bourget	Paris Le Bourget	
ORY	LFPO	Paris/Orly	Paris Orly	Orly
ACY	KACY	Philadelphia/Atlantic City	Atlantic City International	
PHL	KPHL	Philadelphia/Intl	Philadelphia International	
FLR	LIRQ	Pisa/Florence Peretola	Florence Pretola	Peretola
PSA	LIRP	Pisa/Galilei	Pisa	San Giusto
GIG	SBGL	Rio De Janeiro/Galeao	Rio De Janeiro Galeao Intl	Galeao Antonio Carlos Jobim
SDU	SBRJ	Rio De Janeiro/Santos Dumont	Rio De Janeiro Santos Dumont	Santos Dumont
CIA	LIRA	Rome/Ciampino	Rome Ciampino	Ciampino
FCO	LIRF	Rome/Fiumicino	Rome Fiumicino	Fiumicino
SAN	KSAN	San Diego/Intl	San Diego International	
TIJ	MMTJ	San Diego/Tijuana	General Abelardo L. Rodríguez International	
SFO	KSFO	San Francisco/Intl	San Francisco Intl	
OAK	KOAK	San Francisco/Oakland	Oakland Intl	Metropolitan Oakland Intl
SJC	KSJC	San Francisco/San Jose	San Jose Municipal	Norman Y Mineta San Jose Intl
VCP	SBKP	Sao Paulo/Campinas	Campinas Viracopos	Viracopos
CGH	SBSP	Sao Paulo/Congonhas	Sao Paulo Congonhas	Congonhas
GRU	SBGR	Sao Paulo/Guarulhos	Sao Paulo Guarulhos	Guarulhos
GMP	RKSS	Seoul/Gimpo	Seoul Kimpo Intl	Gimpo
ICN	RKSI	Seoul/Incheon	Incheon Intl	
SHA	ZSSS	Shanghai/Hongqiao	Shanghai Hongqiao	Hongqiao Intl
PVG	ZSPD	Shanghai/Pudong	Shanghai Pudong	Pudong
ARN	ESSA	Stockholm/Arlanda	Stockholm Arlanda	Arlanda
BMA	ESSB	Stockholm/Bromma	Bromma	
NYO	ESKN	Stockholm/Skavsta	Skavsta	Nykoeping
VST	ESOW	Stockholm/Vasteras	Vasteras	Vasteras Hasslo
STU	EDDS	Stuttgart/Intl	Stuttgart	
FKB	EDSB	Stuttgart/Karlsruhe Baden Baden	Karlsruhe Baden Baden	Baden Airpark

IATA code	ICAO code	**Airport Name** (Used for the purpose of this research)	**Other Names** (Used in the literature)	
TSA	RCSS	Taipei/Songshan	Taipei Sung Shan	Sungshan
TPE	RCTP	Taipei/Taoyuan	Taipei Chiang Kai Shek	Chiang Kai Shek Intl
TPA	KTPA	Tampa/Intl	Tampa Intl	
SRQ	KSRQ	Tampa/Sarasota	Sarasota Bradenton	
PIE	KPIE	Tampa/St Petersburg	St. Petersburg Clearwater Intl	
IKA	OIIE	Tehran/Imam Khomeini	Teheran Imam Khomeini Intl	Imam Khomeini Intl
THR	OIII	Tehran/Mehrabad	Teheran Mehrabad Intl	Mehrabad Intl
TLV	LLBG	Tel Aviv/Ben Gurion	Tel-Aviv Ben Gurion	Ben Gurion
SDV	LLSD	Tel Aviv/Sde Dov	Tel-Aviv Sde Dov	Sde Dov
HND	RJTT	Tokyo/Haneda	Tokyo Haneda Intl	Tokyo Intl
NRT	RJAA	Tokyo/Narita	Tokyo Narita Intl	Tokyo Narita/New Tokyo Apt.
YTZ	CYTZ	Toronto/City Centre	Toronto City Centre	Toronto Toronto Island
YHM	CYHM	Toronto/Hamilton	Hamilton	Hamilton Civic
YYZ	CYYZ	Toronto/Pearson	Toronto Lester B. Pearson	Lester B Pearson Intl
YXX	CYXX	Vancouver/Abbotsford	Abbotsford	
YVR	CYVR	Vancouver/Intl	Vancouver Intl	
VCE	LIPZ	Venice/Polo	Venice Tessera	Venice Marco Polo
TSF	LIPH	Venice/Treviso	Treviso	Treviso San Angelo
BTS	LZIB	Vienna/Bratislava	Bratislava Ivanka	M R Stefanik
VIE	LOWW	Vienna/Intl	Vienna	Vienna Schwechat
EPMO*	EPMO	Warsaw/Modlin	Modlin	
WAW	EPWA	Warsaw/Okecie	Warsaw Okecie	Okecie
BWI	KBWI	Washington/Baltimore	Baltimore Washington Intl	
IAD	KIAD	Washington/Dulles	Washington Dulles Intl	
DCA	KDCA	Washington/Reagan	Ronald Reagan Washington Natl	Washington National

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Appendix B-2: Airports part of multi-airport systems; primary and secondary airports.

Table 30: Primary airports within the 59 multi-airport systems[1]

Primary Airports within Multi-Airport Systems

Airport IATA code	Airport name	Passenger traffic (2006)	Passenger traffic in the multi-airport system (MAS)	Multi-airport system traffic share
YYZ	Toronto/Pearson	30,966,000	31,493,000	98%
PHL	Philadelphia/Intl	30,604,000	31,482,000	97%
YVR	Vancouver/Intl	17,011,000	17,513,000	97%
DTW	Detroit/Metropolitan	34,646,000	35,726,000	97%
MEL	Melbourne/Tullamarine	20,639,000	21,339,000	97%
AMS	Amsterdam/Schiphol	45,988,000	48,197,000	95%
HAM	Hamburg/Fuhlsbuettel	11,874,000	12,554,000	95%
MCO	Orlando/Intl	33,748,000	35,761,000	94%
TLV	Tel Aviv/Ben Gurion	9,221,000	9,846,000	94%
FRA	Frankfurt/Main	52,810,000	56,581,000	93%
MEX	Mexico City/Intl	24,579,000	26,359,000	93%
OSL	Oslo/Gardermoen	17,672,000	18,972,000	93%
STU	Stuttgart/Intl	10,020,000	10,856,000	92%
CPH	Copenhagen/Kastrup	20,799,000	22,681,000	92%
TPA	Tampa/Intl	18,321,000	20,046,000	91%
DXB	Dubai/Intl	28,788,000	31,853,000	90%
DFW	Dallas/Fort Worth	57,232,000	63,719,000	90%
VIE	Vienna/Intl	16,822,000	18,760,000	90%
GOT	Gothenburg/Landvetter	4,279,000	4,829,000	89%
CLE	Cleveland/Hopkins	10,871,000	12,311,000	88%
IST	Istanbul/Atatuerk	21,265,000	24,182,000	88%
BLQ	Bologna/Intl	4,001,000	4,619,000	87%
FCO	Rome/Fiumicino	30,100,000	35,045,000	86%
BCN	Barcelona/Intl	29,835,000	34,830,000	86%
THR	Tehran/Mehrabad	9,333,000	10,933,000	85%
VCE	Venice/Polo	7,700,000	9,200,000	84%
IAH	Houston/Intercontinental	40,477,000	48,669,000	83%
ARN	Stockholm/Arlanda	17,500,000	21,122,000	83%
SAN	San Diego/Intl	17,299,000	21,047,000	82%
BRU	Brussels/Zaventem	16,587,000	20,382,000	81%
ORD	Chicago/O'Hare	73,851,000	91,581,000	81%
DMK	Bangkok/Don Mueang	41,011,000	51,900,000	79%
ORF	Norfolk/Intl	3,733,000	4,766,000	78%
TPE	Taipei/Taoyuan	22,857,000	29,586,000	77%
CNF	Belo Horizonte/Neves	4,019,000	5,301,000	76%
BOS	Boston/Logan	26,841,000	36,113,000	74%
MAN	Manchester/Intl	22,123,000	30,431,000	73%
GIG	Rio De Janeiro/Galeao	9,323,000	12,885,000	72%
HKG	Hong Kong/Intl	44,020,000	61,913,000	71%
BFS	Belfast/Intl	5,015,000	7,120,000	70%
LAX	Los Angeles/Intl	58,603,000	83,366,000	70%
HND	Tokyo/Haneda	65,225,000	95,261,000	68%
CDG	Paris/de Gaulle	56,808,000	84,307,000	67%
ICN	Seoul/Incheon	27,661,000	41,428,000	67%
PSA	Pisa/Galilei	3,014,000	4,535,000	66%

[1] Data source: (1) for non U.S. airports; International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008, (2) for U.S. airports; Federal Aviation Administration (FAA) Historical records from Terminal Area Forecast (TAF) database, available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: March 2007.

Table 31: Primary airports within the 59 multi-airport systems (cont.)[1]

Primary Airports within Multi-Airport Systems (cont.)

Airport IATA code	Airport name	Passenger traffic (2006)	Passenger traffic in the multi-airport system (MAS)	Multi-airport system traffic share
TXL	Berlin/Tegel	11,768,000	18,416,000	64%
MIA	Miami/Intl	30,939,000	51,241,000	60%
MXP	Milan/Malpensa	21,767,000	36,705,000	59%
EZE	Buenos Aires/Pistarini	7,450,000	12,718,000	59%
PVG	Shanghai/Pudong	26,601,000	45,730,000	58%
DUS	Dusseldorf/Intl	16,510,000	28,970,000	57%
SFO	San Francisco/Intl	32,355,000	56,943,000	57%
CGH	Sao Paulo/Congonhas	18,407,000	36,260,000	51%
ITM	Osaka/Itami	18,948,000	37,733,000	50%
LHR	London/Heathrow	67,339,000	136,891,000	49%
DME	Moscow/Domodedovo	15,370,000	33,082,000	46%
GRU	Sao Paulo/Guarulhos	16,791,000	36,260,000	46%
GLA	Glasgow/Intl	8,820,000	19,822,000	44%
EDI	Glasgow/Edinburgh	8,606,000	19,822,000	43%
KIX	Osaka/Kansai	16,087,000	37,733,000	43%
SHA	Shanghai/Hongqiao	19,128,000	45,730,000	42%
AEP	Buenos Aires/Newbery	5,268,000	12,718,000	41%
FLL	Miami/Fort Lauderdale	20,302,000	51,241,000	40%
JFK	New York/Kennedy	40,900,000	104,202,000	39%
SVO	Moscow/Sheremetyevo	12,595,000	33,082,000	38%
IAD	Washington/Dulles	22,291,000	60,436,000	37%
CGN	Dusseldorf/Cologne Bonn	9,812,000	28,970,000	34%
EWR	New York/Newark	35,257,000	104,202,000	34%
BWI	Washington/Baltimore	20,344,000	60,436,000	34%
FLR	Pisa/Florence Peretola	1,520,000	4,535,000	34%
GMP	Seoul/Gimpo	13,766,000	41,428,000	33%
SXF	Berlin/Schoenefeld	6,013,000	18,416,000	33%
NRT	Tokyo/Narita	30,035,000	95,261,000	32%
ORY	Paris/Orly	25,622,000	84,307,000	30%
BHD	Belfast/City	2,105,000	7,120,000	30%
DCA	Washington/Reagan	17,800,000	60,436,000	29%
SZX	Hong Kong/Shenzen	17,893,000	61,913,000	29%
SDU	Rio De Janeiro/Santos Dumont	3,562,000	12,885,000	28%
LIN	Milan/Linate	9,696,000	36,705,000	26%
LGW	London/Gatwick	34,080,000	136,891,000	25%
LGA	New York/LaGuardia	25,791,000	104,202,000	25%
OAK	San Francisco/Oakland	13,991,000	56,943,000	25%
PLU	Belo Horizonte/Pampulha	1,281,000	5,301,000	24%
TSA	Taipei/Songshan	6,728,000	29,586,000	23%
PHF	Norfolk/News Williamsburg	1,032,000	4,766,000	22%
BKK	Bangkok/Suvarnabhumi	10,888,000	51,900,000	21%

[1] Data source: (1) for non U.S. airports; International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008, (2) for U.S. airports; Federal Aviation Administration (FAA) Historical records from Terminal Area Forecast (TAF) database, available at http://www.apo.data.faa.gov/faatafall.htm, last accessed: March 2007.

Table 32: Secondary airports within the 59 multi-airport systems[1]

Secondary Airports within Multi-Airport Systems

Airport IATA code	Airport name	Passenger traffic (2006)	Passenger traffic in the multi-airport system (MAS)	Multi-airport system traffic share
MDW	Chicago/Midway	17,729,000	91,581,000	19.4%
CRL	Brussels/South Charleroi	3,794,000	20,382,000	18.6%
SJC	San Francisco/San Jose	10,597,000	56,943,000	18.6%
TIJ	San Diego/Tijuana	3,748,000	21,047,000	17.8%
STN	London/Stansted	23,680,000	136,891,000	17.3%
HOU	Houston/Hobby	8,191,000	48,669,000	16.8%
LPL	Manchester/Liverpool	4,962,000	30,431,000	16.3%
TSF	Venice/Treviso	1,500,000	9,200,000	16.3%
VKO	Moscow/Vnukovo	5,116,000	33,082,000	15.5%
PVD	Boston/Providence	5,300,000	36,113,000	14.7%
IKA	Tehran/Imam Khomeini	1,600,000	10,933,000	14.6%
BGY	Milan/Bergamo Orio Al Serio	5,241,000	36,705,000	14.3%
CIA	Rome/Ciampino	4,945,000	35,045,000	14.1%
FRL	Bologna/Forli	618,000	4,619,000	13.4%
PIK	Glasgow/Prestwick	2,394,000	19,822,000	12.1%
SAW	Istanbul/Sabiha Gokcen	2,916,000	24,182,000	12.1%
CAK	Cleveland/Akron-Canton	1,440,000	12,311,000	11.7%
SNA	Los Angeles/Santa Ana	9,497,000	83,366,000	11.4%
GSE	Gothenburg/City	550,000	4,829,000	11.4%
MHT	Boston/Manchester	3,971,000	36,113,000	11.0%
GRO	Barcelona/Gerona	3,614,000	34,830,000	10.4%
BTS	Vienna/Bratislava	1,937,000	18,760,000	10.3%
DAL	Dallas/Love Field	6,487,000	63,719,000	10.2%
SHJ	Dubai/Sharjah	3,064,000	31,853,000	9.6%
LBA	Manchester/Leeds Bradford	2,792,000	30,431,000	9.2%
NYO	Stockholm/Skavsta	1,770,000	21,122,000	8.4%
MMX	Copenhagen/Malmo	1,882,000	22,681,000	8.3%
ONT	Los Angeles/Ontario	6,847,000	83,366,000	8.2%
BMA	Stockholm/Bromma	1,663,000	21,122,000	7.9%
FKB	Stuttgart/Karlsruhe Baden Baden	835,000	10,856,000	7.7%
UKB	Osaka/Kobe	2,697,000	37,733,000	7.1%
DTM	Dusseldorf/Dortmund	2,020,000	28,970,000	7.0%
LTN	London/Luton	9,414,000	136,891,000	6.9%
TRF	Oslo/Sandefjord	1,300,000	18,972,000	6.9%
BUR	Los Angeles/Burbank	5,675,000	83,366,000	6.8%
TLC	Mexico City/Toluca	1,780,000	26,359,000	6.8%
SRQ	Tampa/Sarasota	1,348,000	20,046,000	6.7%
HHN	Frankfurt/Hahn	3,704,000	56,581,000	6.5%
SDV	Tel Aviv/Sde Dov	624,000	9,846,000	6.3%
LBC	Hamburg/Lubeck	680,000	12,554,000	5.4%
SFB	Orlando/Sanford	1,662,000	35,761,000	4.6%
REU	Barcelona/Reus	1,380,000	34,830,000	4.0%
THF	Berlin/Tempelhof	634,000	18,416,000	3.4%
LGB	Los Angeles/Long Beach	2,742,000	83,366,000	3.3%
AVV	Melbourne/Avalon	700,000	21,339,000	3.3%
FNT	Detroit/Bishop	1,080,000	35,726,000	3.0%
VCP	Sao Paulo/Campinas	1,061,000	36,260,000	2.9%
YXX	Vancouver/Abbotsford	502,000	17,513,000	2.9%
ACY	Philadelphia/Atlantic City	877,000	31,482,000	2.8%
EIN	Amsterdam/Eindhoven	1,170,000	48,197,000	2.4%
BVA	Paris/Beauvais	1,876,000	84,307,000	2.2%
ISP	New York/Islip	2,253,000	104,202,000	2.2%
RTM	Amsterdam/Rotterdam	1,037,000	48,197,000	2.2%
NRN	Dusseldorf/Weeze Niederrhein	590,000	28,970,000	2.0%
PIE	Tampa/St Petersburg	376,000	20,046,000	1.9%
BLK	Manchester/Blackpool	552,000	30,431,000	1.8%
LCY	London/City	2,377,000	136,891,000	1.7%
YHM	Toronto/Hamilton	527,000	31,493,000	1.7%

[1] Data source: (same as primary airports). Note: Tampa/St. Petersburg was kept as a secondary airport despite the fact that in 2006 it handled less than 500,000 passengers. It met the 500,000 passenger criteria from 1993 to 2005, as well as in 2007 (e.g. 1,333,000 passengers in 2004, 596,000 in 2005 and 747,000 in 2007).

Table 33: Airports used predominantly for cargo activity (without significant passenger traffic) within or in the vicinity of multi-airport systems[1]

IATA Code	ICAO Code	Metropolitan Region	Country	Airport Name	Total Freight in 2005 (metric tons)	Distance from the center of metropolitan region (miles)
Cargo (only) airports within Multi-Airport Systems						
LGG	EBLG	Brussels	Belgium	Brussels/Liege	325,712	52
AFW	KAFW	Dallas	United States	Dallas/Alliance	220,134	33
Cargo (only) airports in the vicinity of Multi-Airport Systems (beyond 60 miles)						
RFD	KRFD	Chicago	United States	Chicago/Rockford	1,639,323	78
XCR	LFOK	Paris	France	Paris/Vatry	37,670	83

[1] Data sources: (1) for Liege airport; International Civil Aviation Organization (ICAO), ICAO Airports Core Service data, available with MIT Libraries license, last accessed: January 2008, (2) for Vatry, Rockford and Alliance; airport websites.

Appendix B-3: Forms of ownership and management of airports

Airport name	Airport type	Owner	Operator	Form or Ownership & Management
Amsterdam/Schiphol	Primary	Schiphol Group	Schiphol Group	D
Amsterdam/Eindhoven	Secondary	Schiphol Group	Schiphol Group	D
Amsterdam/Rotterdam	Secondary	Schiphol Group	Schiphol Group	D
Bangkok/Suvarnabhumi	Primary	Airports of Thailand	Airports of Thailand	E
Bangkok/Don Mueang	Primary	Airports of Thailand	Airports of Thailand	E
Barcelona/Intl	Primary	Aeropuertos Españoles y Navegación Aérea (AENA)	Aeropuertos Españoles y Navegación Aérea (AENA)	D
Barcelona/Gerona	Secondary	Aeropuertos Españoles y Navegación Aérea (AENA)	Aeropuertos Españoles y Navegación Aérea (AENA)	D
Barcelona/Reus	Secondary	Aeropuertos Españoles y Navegación Aérea (AENA)	Aeropuertos Españoles y Navegación Aérea (AENA)	D
Belfast/Intl	Primary	Abertis Airports / ACDL / TBI (Belfast International Airport Ltd.)	Abertis Airports / ACDL / TBI (Belfast International Airport Ltd.)	F
Belfast/City	Primary	Ferrovial	Ferrovial	F
Belo Horizonte/Neves	Primary	Infraero	Infraero	D
Belo Horizonte/Pampulha	Primary	Infraero	Infraero	D
Berlin/Schoenefeld	Primary		Berlin Airports	D
Berlin/Tegel	Primary		Berlin airports	D
Berlin/Tempelhof	Secondary		Berlin airports	D
Berlin/Eberswalde-Finow	Potential Secondary	Local business interests (acquire option in 2013 by Infratil)	Local (Option by Infratil in 2013)	C
Bologna/Intl	Primary		Aeroporto Guglielmo Marconi di Bologna S.p.A.	E
Bologna/Forli	Secondary		Società Esercizio Aeroporto di Forlì S.p.A.	E
Boston/Logan	Primary	Mass Port Authority	Massport	D
Boston/Manchester	Secondary	City of Manchester	City of Manchester	B
Boston/Providence	Secondary	State of Rhode Island	Rhode Island Airport Corp.	D
Brussels/Zaventem	Primary		The Brussels Airport Company	C
Brussels/South Charleroi	Secondary	Wallonia Government	Wallonia Government	B
Buenos Aires/Newbery	Primary		Aeropuertos Argentina	C
Buenos Aires/Pistarini	Primary		Aeropuertos Argentina	C

Airport name	Airport type	Owner	Operator	Form or Ownership & Management
Chicago/O'Hare	Primary	City of Chicago	The Chicago Airport System Department of Aviation	B
Chicago/Midway	Secondary	City of Chicago	The Chicago Airport System Department of Aviation	B
Copenhagen/Kastrup	Primary		Copenhagen Airports A/S	E
Copenhagen/Malmo	Secondary		Swedish Civil Aviation Administration (Luftfartsverket)	A
Dallas/Fort Worth	Primary	City of Dallas / City of Fort Worth	City of Dallas / City of Fort Worth	B
Dallas/Love Field	Secondary	City of Dallas	City of Dallas	B
Dubai/Intl	Primary		Department of Civil Aviation	A
Dubai/Sharjah	Secondary		Department of Civil Aviation	A
Dusseldorf/Cologne Bonn	Primary	State & Local Public Owners	Flughafen Köln/Bonn GmbH	D
Dusseldorf/Intl	Primary	Landeshauptstadt (state capital) (50%) and Airport Partners GmbH (50%)	Flughafen Düsseldorf GmbH	E
Dusseldorf/Dortmund	Secondary		Flughafen Dortmund GmbH	D
Dusseldorf/Weeze Niederrhein	Secondary		Flughafen Niederrhein GmbH	C
Frankfurt/Main	Primary		Fraport AG	E
Frankfurt/Hahn	Secondary		Fraport AG	E
Frankfurt/Mannheim City	Potential Secondary		Rhein-Neckar Flugplatz GmbH	D
Glasgow/Edinburgh	Primary	BAA Limited	BAA Limited	F
Glasgow/Intl	Primary	BAA Limited	BAA Limited	F
Glasgow/Prestwick	Secondary	Infratil	Infratil	F
Gothenburg/Landvetter	Primary	Swedish Civil Aviation Administration (Luftfartsverket)	Swedish Civil Aviation Administration (Luftfartsverket)	A
Gothenburg/City	Secondary	Luftfartsverket, Volvo, Göteborgs kommun	Cityflygplatsen, Göteborg AB	E
Hamburg/Fuhlsbuettel	Primary	City of Hamburg & Hochtief AirPort GmbH	FHG Flughafen Hamburg GmbH	D
Hamburg/Lubeck	Secondary		Infratil	C
Hong Kong/Intl	Primary		Airport Authority Hong Kong	D
Hong Kong/Shenzen	Primary		Shenzhen Airport Co., Ltd.	E

Airport name	Airport type	Owner	Operator	Form or Ownership & Management
Houston/Intercontinental	Primary	City of Houston	City of Houston	B
Houston/Hobby	Secondary	City of Houston	City of Houston	B
Istanbul/Atatuerk	Primary		TAV Airports Group	F
Istanbul/Sabiha Gokcen	Secondary		HEAS	F
London/Luton	Secondary	ACDL - London Luton Airport Operations Ltd	ACDL - London Luton Airport Operations Ltd	F
London/City	Secondary	AIG, GE Capital & Credit Suisse	AIG, GE Capital & Credit Suisse	F
London/Gatwick	Primary	BAA Limited	BAA Limited	F
London/Heathrow	Primary	BAA Limited	BAA Limited	F
London/Stansted	Secondary	BAA Limited	BAA Limited	F
Los Angeles/Intl	Primary	City of Los Angeles	Los Angeles World Airports (LAWA)	B
Los Angeles/Burbank	Secondary	Burbank - Glendale - Pasadena Airport Authority	Burbank - Glendale - Pasadena Airport Authority	D
Los Angeles/Long Beach	Secondary	City of Long Beach	City of Long Beach	B
Los Angeles/Ontario	Secondary	City of Los Angeles	Los Angeles World Airports (LAWA)	B
Los Angeles/Santa Ana	Secondary	Orange County	Orange County	B
Manchester/Intl	Primary	Manchester Airport Group	Manchester Airport Group	D
Manchester/Blackpool	Secondary	MAR Properties Ltd	MAR Properties Ltd	F
Manchester/Leeds Bradford	Secondary	Leeds Bradford International Airport Limited	Leeds Bradford International Airport Limited	D
Manchester/Liverpool	Secondary	Liverpool Airport plc (Peel Holdings)	Liverpool Airport plc (Peel Holdings)	F
Melbourne/Tullamarine	Primary		Australia Pacific Airports	C
Melbourne/Avalon	Secondary		Linfox	C
Mexico City/Intl	Primary		Grupo Aeroportuario de la Ciudad de México	E
Mexico City/Toluca	Secondary		Grupo Aeroportuario de la Ciudad de México	E
Miami/Fort Lauderdale	Primary	Broward County	Broward County	B
Miami/Intl	Primary	Dade County Aviation Department	Miami-Dade County Aviation Department	B
Milan/Bergamo Orio Al Serio	Secondary		SACBO (Società Aeroporto Civile Bergamo Orio al Serio)	B
Milan/Linate	Primary	City of Milano (84,56%), Province of Milan (14,56%), Privately owned (0,88%)	SEA - Aeroporti di Milano	E
Milan/Malpensa	Primary		SEA - Aeroporti di Milano	E

Airport name	Airport type	Owner	Operator	Form or Ownership & Management
Moscow/Domodedovo	Primary	Russian State	East Line Group	C
Moscow/Sheremetyevo	Primary		International Airport Sheremetyevo	D
Moscow/Ostafievo	Potential Secondary	Gazpromavia	GAZPROMAVIA Aviation Company Ltd	F
Moscow/Vnukovo	Secondary		Vnukovo Airport	D
New York/Newark	Primary	Port Authority of New York and New Jersey (PANYNJ)	Port Authority of New York and New Jersey (PANYNJ)	D
New York/Kennedy	Primary	Port Authority of New York and New Jersey (PANYNJ)	Port Authority of New York and New Jersey (PANYNJ)	D
New York/LaGuardia	Primary	Port Authority of New York and New Jersey (PANYNJ)	Port Authority of New York and New Jersey (PANYNJ)	D
New York/Islip	Secondary	Town of Islip	Town of Islip	B
Norfolk/Intl	Primary		Norfolk Airport Authority	D
Norfolk/News Williamsburg	Primary		The Peninsula Airport Commission	B
Orlando/Intl	Primary	Orlando Aviation Authority	Greater Orlando Aviation Authority	B
Orlando/Melbourne	Potential Secondary	City of Melbourne	City of Melbourne	B
Orlando/Sanford	Secondary	Sanford Airport Authority	TBI / Abertis	C
Osaka/Itami	Primary	Ministry of Land, Infrastructure and Transport & Osaka International Airport Terminal Co. Ltd.	Ministry of Land, Infrastructure and Transport & Osaka International Airport Terminal Co. Ltd.	A
Osaka/Kansai	Primary		Kansai International Airport Co., Ltd.	E
Osaka/Kobe	Secondary		Other	B
Oslo/Gardermoen	Primary		Oslo Lufthavn	D
Oslo/Sandefjord	Secondary	Sandefjord Lufthavn AS	Sandefjord Lufthavn AS	E
Oslo/Moss Rygge	Potential Secondary	Rygge sivile lufthavn	Rygge sivile lufthavn	F
Paris/de Gaulle	Primary		Aéroports de Paris	E
Paris/Orly	Primary		Aéroports de Paris	E
Paris/Beauvais	Secondary		Chambre de Commerce et d'Industrie (CCI) de l'Oise	B
Pisa/Florence Peretola	Primary		Aeroporto di Firenze	F
Pisa/Galilei	Primary		SOCIETA' AEROPORTO TOSCANO (S.A.T.)	F
Rio De Janeiro/Galeao	Primary	Infraero and Brazilian Air Force	Infraero and Brazilian Air Force	D
Rio De Janeiro/Santos Dumont	Primary	Infraero	Infraero and Brazilian Air Force	D

Airport name	Airport type	Owner	Operator	Form or Ownership & Management
Rome/Fiumicino	Primary	ADR Aeroporti di Roma S.p.A.	ADR Aeroporti di Roma S.p.A.	F
Rome/Ciampino	Secondary	ADR Aeroporti di Roma S.p.A.	ADR Aeroporti di Roma S.p.A.	F
San Francisco/Oakland	Primary	The Port of Oakland	The Port of Oakland	D
San Francisco/Intl	Primary	County of San Francisco	San Francisco Airports Commission	B
San Francisco/San Jose	Secondary	City of San Jose	The City of San Jose Airport Commission	B
Sao Paulo/Congonhas	Primary	Infraero	Infraero	D
Sao Paulo/Guarulhos	Primary	Infraero	Infraero	D
Sao Paulo/Campinas	Secondary	Infraero	Infraero	D
Seoul/Gimpo	Primary		Korea Airports Corporation	D
Seoul/Incheon	Primary	Incheon International Airport Corporation (IIAC)	Incheon International Airport Corporation (IIAC)	D
Shanghai/Pudong	Primary		Shanghai Airport Authority	E
Shanghai/Hongqiao	Primary		Shanghai Airport Authority	E
Stockholm/Arlanda	Primary	Swedish Civil Aviation Administration (Luftfartsverket)	Swedish Civil Aviation Administration (Luftfartsverket)	A
Stockholm/Bromma	Secondary	Swedish Civil Aviation Administration (Luftfartsverket)	Swedish Civil Aviation Administration (Luftfartsverket)	A
Stockholm/Skavsta	Secondary	Airport Concessions and Development Limited (ACDL) - Abertis	Airport Concessions and Development Limited (ACDL) - Abertis	F
Stockholm/Vasteras	Potential Secondary	Swedish Civil Aviation Administration (Luftfartsverket)	Swedish Civil Aviation Administration (Luftfartsverket)	A
Stuttgart/Intl	Primary	Baden-Württemberg Land (50 %), Stuttgart City (50 %) ?	Flughafen Stuttgart GmbH	B
Stuttgart/Karlsruhe Baden Baden	Secondary	Baden-Airpark GmbH	Baden-Airpark GmbH	C
Taipei/Taoyuan	Primary	Civil Aeronautics Administration	Civil Aeronautics Administration	A
Taipei/Songshan	Primary	Civil Aeronautics Administration	Civil Aeronautics Administration	A
Tampa/Intl	Primary	Hillsborough County Aviation Authority	Hillsborough County Aviation Authority	D
Tampa/St Petersburg	Secondary	County of Pinellas	County of Pinellas	B
Tampa/Sarasota	Secondary	Sarasota Manatee Airport Authority	Sarasota Manatee Airport Authority	D
Tehran/Mehrabad	Primary		Iran Airports Company	D
Tehran/Imam Khomeini	Secondary		TAV (Tepe-Akfen-Vie)	F

Airport name	Airport type	Owner	Operator	Form or Ownership & Management
Tel Aviv/Ben Gurion	Primary		Israel Airports Authority	D
Tel Aviv/Sde Dov	Secondary		Israel Airports Authority	D
Tokyo/Haneda	Primary		Tokyo Aviation Bureau, Ministry of Land, Infrastructure and Transport (airfield); Japan Airport Terminal Co., Ltd. (terminals)	A
Tokyo/Narita	Primary		Narita International Airport Corporation (NAA)	E
Toronto/Hamilton	Secondary	City of Hamilton	Tradeport International Corp.	C
Toronto/City Centre	Potential Secondary	Toronto Port Authority	Toronto Port Authority	D
Toronto/Pearson	Primary	Transport Canada	Greater Toronto Airports Authority (GTAA)	D
Vancouver/Intl	Primary	Transport Canada	Vancouver Airport Services (YVRAS)	C
Vancouver/Abbotsford	Secondary	City of Abbotsford	City of Abbotsford	B
Venice/Polo	Primary		SAVE S.p.A.	E
Venice/Treviso	Secondary		Aer Tre S.P.A.	E
Vienna/Intl	Primary		Flughafen Wien AG	E
Vienna/Bratislava	Secondary		Airport Bratislava, a.s. (BTS)	D
Washington/Baltimore	Primary	State of Maryland	Maryland Aviation Administration	B
Washington/Reagan	Primary	Metropolitan Washington Airports Authority	Metropolitan Washington Airports Authority	D
Washington/Dulles	Primary	Metropolitan Washington Airports Authority	Metropolitan Washington Airports Authority	D

Appendix C: Database of Cases of Multi-Airport Systems

Case #	World Region	Metropolitan Area	Country
C-1	Asia-Pacific	Bangkok	Thailand
C-2	Asia-Pacific	Hong Kong	China
C-3	Asia-Pacific	Melbourne	Australia
C-4	Asia-Pacific	Osaka	Japan
C-5	Asia-Pacific	Seoul	South Korea
C-6	Asia-Pacific	Shanghai	China
C-7	Asia-Pacific	Taipei	China
C-8	Asia-Pacific	Tokyo	Japan
C-9	Europe	Amsterdam	Netherlands
C-10	Europe	Barcelona	Spain
C-11	Europe	Belfast	United Kingdom
C-12	Europe	Berlin	Germany
C-13	Europe	Bologna	Italy
C-14	Europe	Brussels	Belgium
C-15	Europe	Copenhagen	Danmark
C-16	Europe	Dusseldorf	Germany
C-17	Europe	Frankfurt	Germany
C-18	Europe	Glasgow	United Kingdom
C-19	Europe	Gothenburg	Sweden
C-20	Europe	Hamburg	Germany
C-21	Europe	Istanbul	Turkey
C-22	Europe	London	United Kingdom
C-23	Europe	Manchester	United Kingdom
C-24	Europe	Milan	Italy
C-25	Europe	Moscow	Russia
C-26	Europe	Oslo	Norway
C-27	Europe	Paris	France
C-28	Europe	Pisa	Italy
C-29	Europe	Rome	Italy
C-30	Europe	Stockholm	Sweden
C-31	Europe	Stuttgart	Germany
C-32	Europe	Venice	Italy
C-33	Europe	Vienna	Austria
C-34	Latin America	Belo Horizonte	Brazil
C-35	Latin America	Buenos Aires	Argentina
C-36	Latin America	Mexico	Mexico
C-37	Latin America	Rio de Janeiro	Brazil
C-38	Latin America	Sao Paulo	Brazil
C-39	Middle East	Dubai	United Arab Emirates
C-40	Middle East	Tehran	Iran
C-41	Middle East	Tel Aviv	Israel
C-42	North America	Los Angeles	United States
C-43	North America	New York	United States
C-44	North America	Washington	United States
C-45	North America	San Francisco	United States
C-46	North America	Boston	United States
C-47	North America	Tampa	United States
C-48	North America	Miami	United States
C-49	North America	Norfolk	United States
C-50	North America	Chicago*	United States
C-51	North America	Cleveland	United States
C-52	North America	Dallas*	United States
C-53	North America	Detroit	United States
C-54	North America	Houston	United States
C-55	North America	Orlando	United States
C-56	North America	Philadelphia	United States
C-57	North America	San Diego	United States
C-58	North America	Toronto	Canada
C-59	North America	Vancouver	Canada

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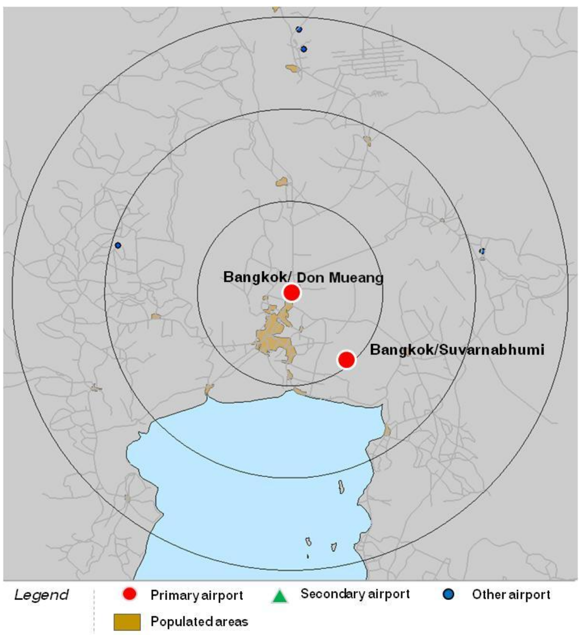
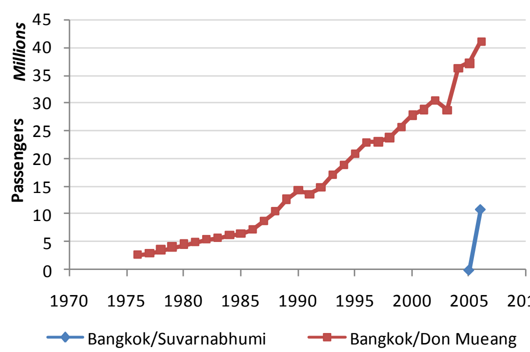
Appendix C-1: Asia/Pacific - Bangkok (Thailand)

The multi-airport system that serves the metropolitan region of Bangkok is composed two primary airports; Bangkok/Don Mueang (DMK-VTBD) and Bangkok/Suvarnabhumi (BKK-VTBS). Bangkok/Don Mueang was the original airport in the region. The construction of Bangkok/Suvarnabhumi was achieved in 2006 and it has become a primary airport in 2006/2007, after the transfer of traffic from Bangkok/Don Mueang.





a. Bangkok/Don Mueang (DMK): Original airport (primary)

Bangkok/Don Mueang is located 13 miles north of the center of Bangkok. It was built in 1914 and commercial traffic started in 1924. The airport temporally closed between 2006 and 2007 when Bangkok/Suvarnabhumi opened.

Congestion of primary airports and limitations of existing airports: Bangkok/Don Mueang was assessed by Airport of Thailand as; "overloaded and not expandable"[1].

[1] Source: Airport of Thailand, available at: http://www.airportsuvarnabhumi.com/, last accessed; March 2008.

Transfer of flights and reopening of the airport: When Bangkok/Suvarnabhumi opened in 2006, Bangkok/Don Mueang was temporarily closed. However, the higher costs of operation to airlines as well as safety concerns at Bangkok/Suvarnabhumi caused Bangkok/Don Mueang to become more attractive to airlines. This was especially true for low-cost carriers. The original deserted airport was an opportunity for low-cost carriers. In addition, it was closer to the center of Bangkok than the new airport[1]. In 2007, the airport was re-opened. Airports of Thailand (i.e. the operator of both Bangkok/Don Mueang and Bangkok/Suvarnabhumi) expressed intention to use Don Muang for low-cost carrier traffic and international flights to delay the expansion of Bangkok/Suvarnabhumi. In 2007, Bangkok/Don Mueang was used by three carriers Thai Airways International (THAI), One-Two-Go and Nok Air[2].

b. Bangkok/Suvarnabhumi (BKK): Primary airport emerged through the construction of a new airport

Bangkok/Suvarnabhumi is located 15 miles south east of the center of the Bangkok. It was built in 2006 and now serves as the main international traffic airport in the region. Bangkok/Don Mueang serves mostly domestic non-connecting flights.

Identification of a need to build a new airport: cf. Bangkok/Don Mueang.

Planning, Financing and Construction of new airport: In 1996, the New Bangkok International Airport Company (NBIA) was formed to build a second airport in the region. Construction started in 2002 (i.e. the construction was delayed due to the Asian financial crisis of 1997). Bangkok/Suvarnabhumi finally opened in 2006.

During the year following the opening of the airport, several technical and infrastructure related problems (i.e. quality of the pavement of the runway and taxiways)

[1] Note: Similar dynamic as the one observed for Houston, Dallas and Chicago multi-airport systems.
[2] Source: Airport of Thailand, available at: http://www.airportsuvarnabhumi.com/, last accessed; March 2008.

disrupted operations of the airport. These problems also contributed to the motivation to reopen Bangkok/Don Mueang[1].

Transfer of traffic/Entry of carriers: Following the opening of the airport in 2006, all flights were transferred from Bangkok/Don Mueang to Bangkok/Suvarnabhumi[2].

Congestion of primary airports and limitations of existing airports: cf. Bangkok/Don Mueang

[1] Source: Airport Technology, Industry Projects page; Suvarnabhumi Airport (BKK/VTBS) Bangkok, Thailand, available at: http://www.airport-technology.com/projects/bangkok/, last accessed; April 2008.
[2] Ibid.

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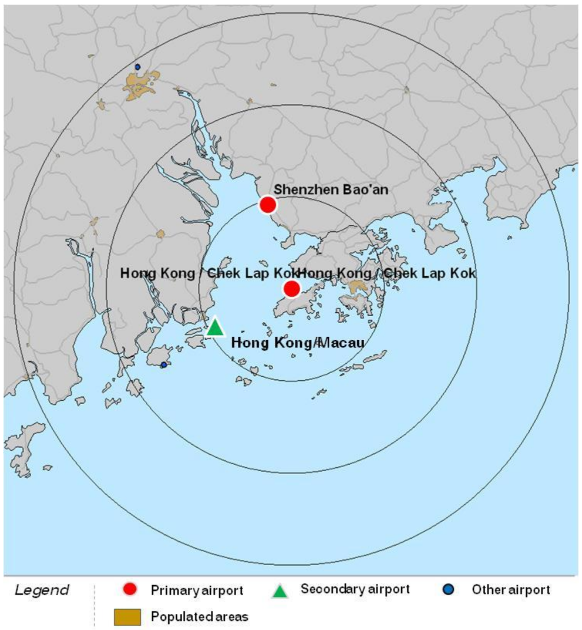
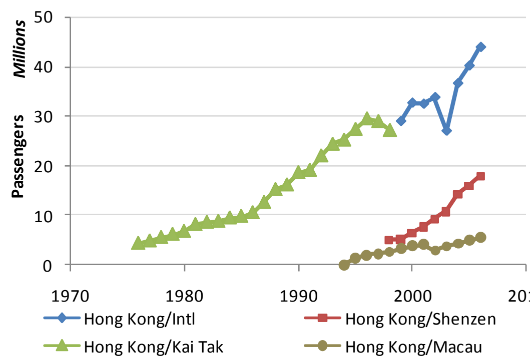
Appendix C-2: Asia/Pacific - Hong Kong (China)

The multi-airport system serving the metropolitan region of Hong Kong is composed of two primary airports; Hong Kong/Intl (HKG-VHHH) and Hong Kong/Shenzen (SZX-ZGSZ). Historically, the region was also served by Hong Kong/Kai Tak that closed in 1998.





a. Hong Kong/Kai Tak (closed): Closed airport

Hong Kong/Kai Tak was the original primary airport serving the Hong Kong metropolitan region and remained in operations from 1925 until 1998[1]. It was located 3 miles from the center of Hong Kong.

Limitations of existing airports: The airport footprint was constrained by urban development and terrain limitations[2].

[1] Source: The Government of the Hong Kong Special Administrative Region, Civil Aviation Department website, Hong Kong/Kai Tak page, available at: http://www.cad.gov.hk/english/kaitak.html, last accessed; April 2008.
[2] Ibid.

b. Hong Kong/Intl (HKG): Primary airport emerged through the construction of a new airport

Hong Kong/Intl is located 16 miles from the center of the Hong Kong. It was opened in 1998.

Identification of a need to build a new airport: cf. Hong Kong/Kai Tak limitations.

Planning, Financing and Construction of new airport: Hong Kong/Intl was built on a largely artificial island reclaimed. Hong Kong/Intl handled 44 million passengers in 2006. With the opening of the second runway in May 1999, the airport has been further developed in stages to cater for increasing air traffic demand[1].

Transfer of traffic/Entry of carriers: All traffic was transferred to Hong Kong/Intl as Hong Kong/Kai Tak closed in 1998.

Congestion of primary airports and limitations of existing airports: cf. Hong Kong/Kai Tak limitations.

c. Hong Kong/Shenzen (SZX): Primary airport emerged through the construction of a new airport

Hong Kong/Shenzen is located 33 miles from the center of the Hong Kong, in a coastal plain of the east bank of Pearl River Estuary. It is 20 miles from the city of Shenzhen. It opened in 1991[2].

Identification of a need to build a new airport: It was built to supported economic growth in the Pearl River Delta, one of three central belts with most rapid development of economy in China[3].

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[1] Source: The Government of the Hong Kong Special Administrative Region, Civil Aviation Department website, Hong Kong/Intl page, available at: http://www.cad.gov.hk/english/cheklapkok.html, last accessed; April 2008.
[2] Source: Shenzen International Airport website, available at: http://eng.szairport.com/, last accessed; April 2008.
[3] Ibid.

Planning, Financing and Construction of new airport: Hong Kong/Shenzen opened in 1991. It was originally built with one runway. A second runway and a new terminal area are scheduled to enter in service in 2011[1].

Transfer of traffic/Entry of carriers: N/A

Congestion of primary airports and limitations of existing airports: N/A (cf. Identification of a need to build a new airport).

a. Hong Kong/Macau (HKG): Secondary airport emerging through the construction of a new airport

Hong Kong/Macau is located 28 miles from the center of the Hong Kong. It was opened in 1995.[2] It links the Pearl River Delta to the rest of Macau's hinterland (i.e. Zhuhai which is one of China's Special Economic Zones).

Planning, Financing and Construction of new airport: Hong Kong/Macau's runway was built on a strip of reclaimed land in the sea. Phase one of the airport is equipped with passenger and cargo facilities designed to handle six million passengers[3].

Transfer of traffic/Entry of carriers: N/A

[1] Ibid.
[2] Source: Macau International Airport website, *"Introduction to Macau International Airport - Airport History & Background",* available at: http://www.macau-airport.com/en/h04/01_history_background.php, last accessed; April 2008.
[3] Ibid.

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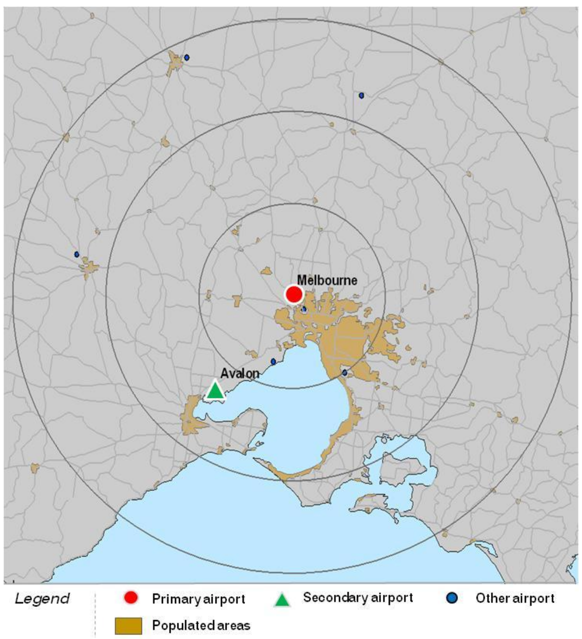
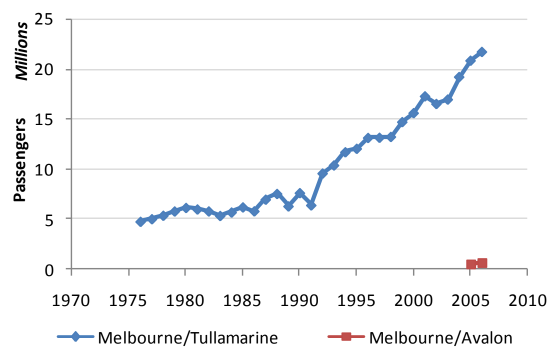
Appendix C-3: Asia/Pacific - Melbourne (Australia)

Melbourne multi-airport system is composed of two key airports; on primary airport, Melbourne/Tullamarine (MEL - YMML) and one secondary airport, Melbourne/Avalon (AVV-YMAV). Melbourne/Tullamarine is the original airport in the region and Melbourne/Avalon emerged as a secondary airport in the 1990s.





a. Melbourne/Tullamarine (MLB): Primary airport emerged through the construction of a new airport

The construction of Melbourne/Tullamarine was achieved in 1970[1]. It was built to replace Essendon airport at which the runways were too short to accommodate jet age aircraft (e.g. Boeing 747). Traffic was displaced from Essendon in 1970. Melbourne/Tullamarine is now the second busiest airport in Australia with 21.6 million passengers in 2006, after Sydney International airport.

Role of ownership and management of airports: In 1997, a number the Australian government privatized in 1997, a number of airports, including Melbourne/Tullamarine. The airport is leased to the Australia Pacific Airports Corporation Limited (APAC) under

[1] Source: Airport Technology, Industry Projects page; Melbourne Airport (MEL/YMML), Victoria, Australia, available at; http://www.airport-technology.com/projects/melbourne/, last accessed; April 2008.

a 50-year long-term lease from the Federal Government, with an option for a further 49 years.

b. Melbourne/Avalon (AVV): Emerged secondary airport

Melbourne/Avalon is used as a secondary airport in the Melbourne metropolitan region. The airport is located 32 miles southwest of Melbourne/Tullamarine and 31 miles southwest of Melbourne. Melbourne/Avalon was built in 1953[1].

Entry of carriers (e.g. low-cost carriers): In 2004, Jetstar Airways, a low cost subsidiary of Qantas, started to offer domestic service (e.g. to Sydney, Brisbane, Perth and Adelaide) from Melbourne/Avalon[2].

Changes of airport status; conversion from military to civil status: Melbourne/Avalon was constructed in 1953 as a military aircraft production facility and was used until the 1980s. The airport was later used as a maintenance facility until 1996. The Australian government converted the airport to civil use in 1997 and sold it to Lindsay Fox, an infrastructure and transport investment company[3].

Upgrade of airport infrastructure: Since the privatization of the airport infrastructure improvements have been performed. Melbourne/Avalon is scheduled to receive a $10 million dollar new terminal, and potentially an international terminal.

Presence of secondary basins of population: Melbourne/Tullamarine also serves the secondary basin of population of Geelong, located south of the airport, which had a population of 160,991 in 2006[4].

Congestion of primary airports: N/A

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[1] Source: Melbourne/Avalon website, available at: http://www.avalonairport.com.au/, last accessed; March 2008.
[2] Ibid.
[3] Ibid.
[4] Data source: Australian Bureau of Statistics, (2006), Census Quick Stats, Geelong Statistical District.

Role of ownership and management of airports: Melbourne/Avalon was acquired in 1997 by an infrastructure and transport investment company; Linfox. As of 2008, Linfox operated both Melbourne/Avalon and Essendon airports. Both airports provide logistics access for domestic and international airfreight, properties for aircraft maintenance, training or logistics purposes. Additionally, these airports are being used for extensive property development[1].

[1] Source: Linfox website, available at: http://www.linfox.com/Airports/, last accessed; March 2008.

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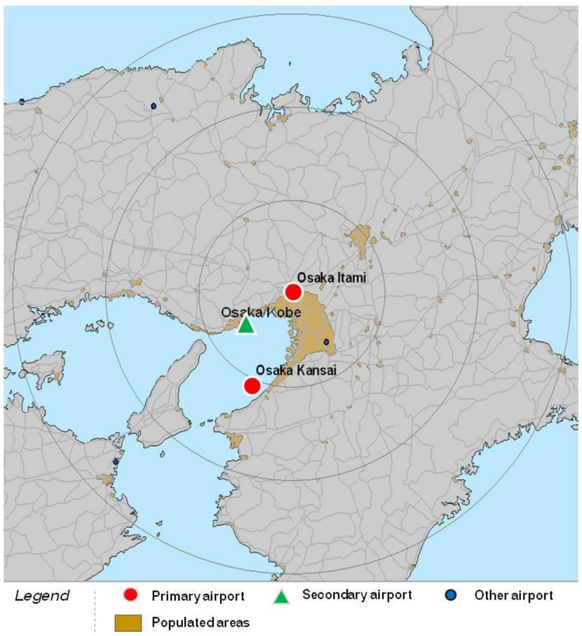
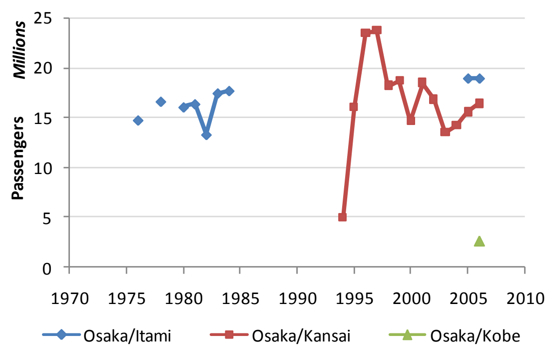
Appendix C-4: Asia/Pacific - Osaka (Japan)

The multi-airport system that serves the Osaka metropolitan region is composed of two primary airports; Osaka/Itami (ITM-RJOO) and Osaka/Kansai (KIX-RJBB). Osaka/Itami is the original primary airport in the metropolitan region while Osaka/Kansai was constructed in 1994. In addition, this multi-airport system also features one secondary airport; Osaka/Kobe (UKB-RJBE) which was also recently built.





a. Osaka/Itami (ITM): Original airport (primary)

Osaka/Itami is located 11 miles from the center of the city of Osaka. It opened in 1939 and was taken over by U.S. control until 1958. Until the opening of Osaka/Kansai, it has served the role of major international airport in the region.

Congestion of primary airports: In the 1970s, the potential expansion of the airport was limited due to urban encroachment and opposition from local communities. The footprint of Osaka/Itami (i.e. 317 hectares)[1] was also limiting any expansion project. Due to the expansion of Osaka/Kansai and the construction of Osaka/Kobe additional capacity is now available at Osaka/Itami.

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[1] Source: Dempsey, P., *"Airport planning and development handbook; a global survey"*, Mc Graw-Hill, New York, 1999.

Closure of the primary airport: Plans to close Osaka/Itami following the opening of Osaka/Kansai were established. However, nearby communities opposed such a move for economic reasons. Osaka/Itami retained domestic traffic after the opening of Osaka/Kansai airport in 1994.

b. Osaka/Kansai (KIX): Primary airport emerged through the construction of a new airport

Osaka/Kansai is located 20 miles from the center Osaka. It was opened in 1994 to accommodate demand that could not be met at Osaka/Itami which was the only primary airport in the region at the time[1].

Identification of a need to build a new airport: In the late 1960s, the potential expansion Osaka/Itami was limited due to urban encroachment and opposition from local communities. Due to these constraints, the planning process for the construction of a new airport started. The construction of Osaka/Kansai was also a conducted to ensure the economic position of the Osaka region[2].

Planning, Financing and Construction of new airport: In 1968, the Ministry of Transport (MOT) began surveying eight proposed airport sites. In 1981, the Ministry of Transport presented a set of proposals to the three prefectural governments (Osaka, Hyogo and Wakayama Prefectures): "Airport Plan for Kansai International Airport", "Kansai International Airport Environmental Impact Assessment" and "Regional Development Plan." In 1984, Kansai International Airport Co., Ltd. (KIAC) was founded. The construction began in 1987 and led to the opening of Osaka/Kansai in 1994[3].

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[1] Source: Kansai International Airport Co., Ltd. website, “History”, available at: http://www.kiac.co.jp/en/company/history.html, last accessed; April 2008.

[2] Source: Dempsey, P., *“Airport planning and development handbook; a global survey”*, Mc Graw-Hill, New York, 1999, p. 437.

[3] Source: Kansai International Airport Co., Ltd. website, “History”, available at: http://www.kiac.co.jp/en/company/history.html, last accessed; April 2008.

Transfer of traffic/Entry of carriers: All international flights were transferred from Osaka/Itami to Osaka/Kansai in 1994.

Congestion of primary airports and limitations of existing airports: cf. Osaka/Itami

Availability and acquisition of land area in the metropolitan region: In 1987, the governor of Osaka Prefecture licensed the company to carry out reclamation work in the public waters for construction of the airport[1]. The decision and trend to built airports on reclaimed sea area is believed to be due to the previous history of airport land acquisition for airport in Japan (cf. Tokyo/Narita).

c. *Osaka/Kobe (UKB): Secondary airport emerged through the construction of a new airport*

Osaka/Kobe is located 16 miles from the center of the city of Osaka.

Identification of a need to build a new airport: N/A

Planning, Financing and Construction of new airport: In the 1970s, when Osaka/Kansai was in process, there was a plan to establish the airport at the current location of Osaka/Kobe[2]. However, the municipality of Kobe rejected the plans arguing that the site was too close to the city of Kobe. Once Osaka/Kansai was built the Kobe municipality decided to fund the construction of another airport, despite much objection from the central government.

Transfer of traffic/Entry of carriers: No formal process of transfer of traffic was established.

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[1] Source: Kansai International Airport Co., Ltd. website, "History", available at: http://www.kiac.co.jp/en/company/history.html, last accessed; April 2008.
[2] Ibid.

Forecast of future passenger traffic within the metropolitan region: N/A

Congestion of primary airports: Because of capacity at Osaka/Kansai, the need to build a new airport in the metropolitan region was not striking.

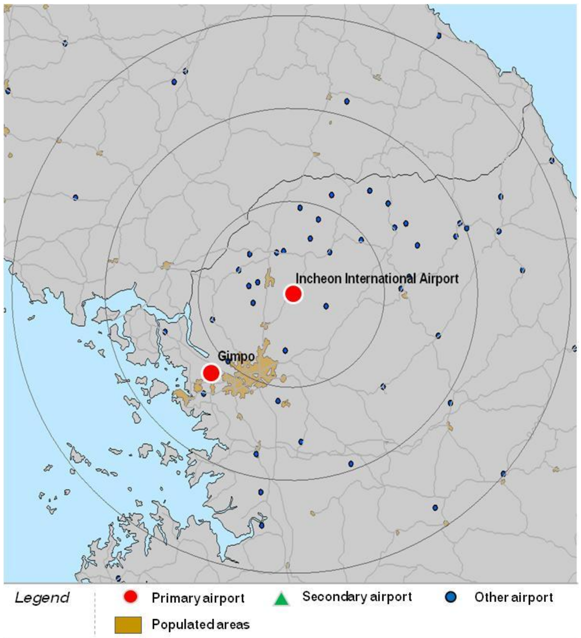
Limitations of existing airports: cf. Osaka/Kansai

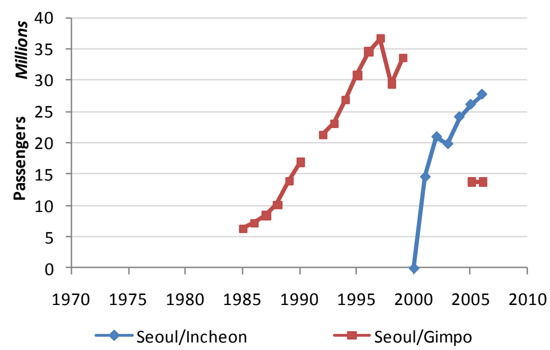
Availability and acquisition of land area in the metropolitan region: The land was available and was originally a selected site in the planning process of Osaka/Kansai[1].

[1] Source: Kansai International Airport Co., Ltd. website, "History", available at: http://www.kiac.co.jp/en/company/history.html, last accessed; April 2008.

Appendix C-5: Asia/Pacific - Seoul (South Korea)

The multi-airport system that serves the Seoul metropolitan region is composed of two primary airports; Seoul/Gimpo (GMP-RKSS) (original airport) and Seoul/Incheon (ICN-RKSI) (primary airport emerged through the construction of a new airport).





a. Seoul/Gimpo (GMP): Original airport (primary)

Seoul/Gimpo is located 10 miles from the center of the city of Seoul. It was built by the Japanese army in 1939 as a military airfield[1]. Gimpo International Airport has been the gateway to Seoul and primary airport in the region until the construction of Seoul/Incheon. After the construction of Seoul/Incheon, international traffic was transferred from the Seoul/Gimpo. It now serves mostly domestic traffic.

Congestion of primary airports and limitations of existing airports: The airport could not be expanded to accommodate projected traffic growth in the region. In the early 2000s, Seoul/Gimpo was becoming congested. According to the 2003, Airport Capacity Demand / Demand Profiles report[2], the runway of Seoul/Gimpo were "near saturated at

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[1] Source: Gimpo International Airport, airport information page , available at : http://gimpo.airport.co.kr/eng/info/information.jsp, last accessed; March 2008.

[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

peak hours" in 2001. The capacity at Seoul/Gimpo was primarily constrained by noise, ATC and runway considerations.

b. *Seoul/Incheon (ICN): Primary airport emerged through the construction of a new airport*

Seoul/Incheon is located 9 miles from the center of Seoul. Its construction was achieved in 2001[1]. It is now used as a primary airport, mostly for international traffic.

Forecast of future passenger traffic within the metropolitan region and identification of a need to build a new airport: After 1988 Olympics, international air traffic to Korea was growing at a strong rate. In the late 1980s, the growth of demand for air transportation coupled with limited ability to accommodate traffic at Seoul/Gimpo motivated the need for a second airport in the metropolitan region.

Planning, Financing and Construction of new airport: The construction of the airport began in 1992. The construction of the second phase was initiated in 2002.

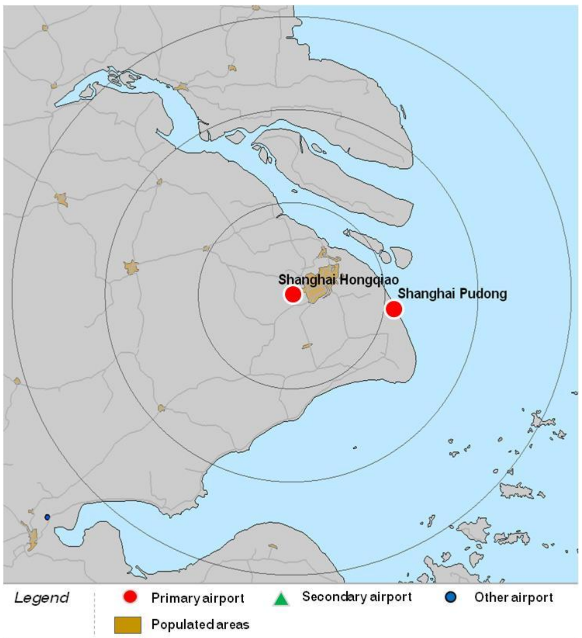
Transfer of traffic/Entry of carriers: All the international traffic was transferred from Seoul/Gimpo to Incheon in 2001.

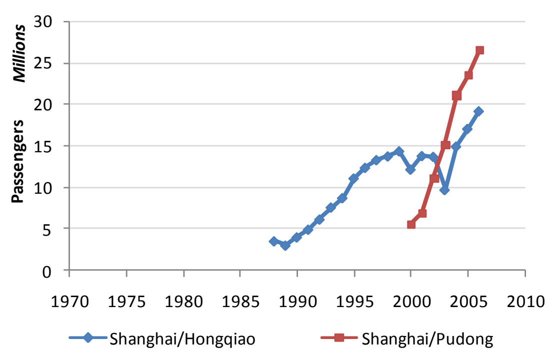
Congestion of primary airports and limitations of existing airports: cf. Seoul/Gimpo

[1] Source: Incheon International Airport, airport information page, available at; http://www.airport.kr/iiacms/pageWork.iia?_scode=C1207010101&fake=1208023652956, last accessed; April 2008.

Appendix C-6: Asia/Pacific - Shanghai (China)

The multi-airport system that serves the Shanghai metropolitan region is composed of two primary airports; Shanghai/Hongqiao (SHA-ZSSS) and Shanghai/Pudong (PVG-ZSPD). Shanghai/Hongqiao was the original airport serving the region. Shanghai/Pudong has emerged as a primary airport in the region after its construction in 1999.





a. Shanghai/Hongqiao (SHA): Original airport (primary)

Shanghai/Hongqiao is located 8 miles west of the center of the city of Shanghai. It is serving mostly domestic traffic (i.e. international flights are handled at Shanghai/Pudong).

Limitations: Shanghai/Hongqiao has only one runway and one taxiway[1] and its expansion is constrained by surrounding urban development.

Role of ownership and management of airports: Shanghai/Hongqiao as well as Shanghai/Pudong are operated by the same authority; Shanghai Airport Authority.

[1] Source: Shanghai Airport Authority, Shanghai/Hongqiao page, available at: http://www.shanghaiairport.com/en/hq.jsp?categoryId=OUT_CON_B0205, last accessed; March 2008.

b. Shanghai/Pudong (PVG): Primary airport emerged through the construction of a new airport

Shanghai/Pudong is located 20 miles east of the center of the city of Shanghai. It was built in 1999 to accommodate growing demand for transportation in the metropolitan region.

Identification of a need to build a new airport & limitations of existing airports: In the 1990s, the projections of growing demand in the region coupled with limited expansion at Shanghai/Hongqiao due to urban development surrounding the airport motivated the need for a second airport in the region.

Planning, Financing and Construction of new airport: The first phase of development started in 1997 and was completed in 1999. In this first phase, one single runway was constructed. A second runway was developed in 2005 and a third runway opened in 2008[1].

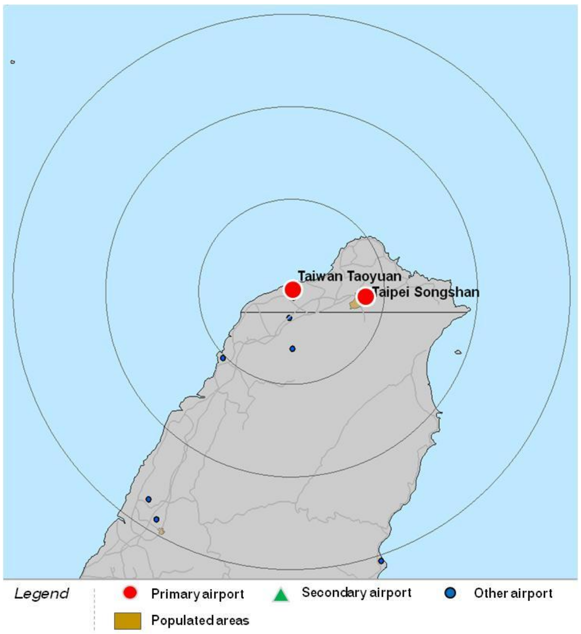
Transfer of traffic/Entry of carriers: All international flights were transferred from Shanghai/Hongqiao to Shanghai/Pudong in 1999.

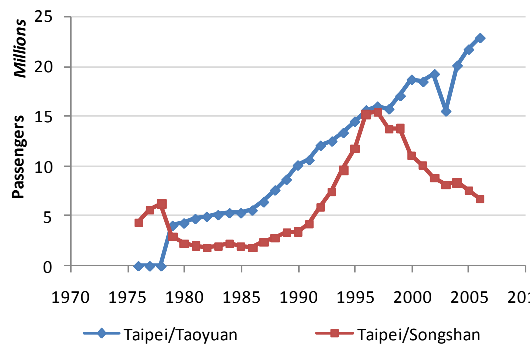
Congestion of primary airports: cf. Shanghai/Hongqiao
Limitations of existing airports: cf. Shanghai/Hongqiao

[1] Source: Shanghai Airport Authority, available at: http://www.shanghaiairport.com/, last accessed; March 2008.

Appendix C-7: Asia/Pacific - Taipei (China)

The multi-airport system that serves the Taipei metropolitan region is composed of two primary airports; Taipei/Songshan (TSA-RCSS) and Taipei/Taoyuan (TPE-RCTP). Taipei/Songshan was the original airport in the region while Taipei/Taoyuan was built in 1979.





a. Taipei/Songshan (TSA): Original airport (primary)

Taipei/Songshan is located 3 miles from the center of Taipei. The airport was originally a military base and was used jointly (i.e. civil and military) since 1950. Today, the airport is mostly used for domestic activities[1].

Congestion of primary airports and limitations of existing airports: Taipei/Songshan was constrained by capacity in the 1970s. In addition, the runways (i.e. the longest runway today is 8,547 ft long) were too short to accommodate wide-body jets.

In addition, Taipei/Songshan was reaching saturation. Some efficiency improvements were made to better utilize available space. However, the problems persisted because of continuing growth of traffic[2].

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[1] Source: Taipei Songshan Airport website, *"A Review: 50 Years of the Taipei Songshan Airport"*, available at; http://www.tsa.gov.tw/2005tax/english/e-50y.htm, last accessed; April 2008.

[2] Ibid.

b. Taipei/Taoyuan (TPE): Primary airport emerged through the construction of a new airport

Taipei/Taoyuan is located 17 miles west from the center of Taipei. It opened in 1979.

Identification of a need to build a new airport: In the 1970s, Taipei/Songshan was constrained both in terms of capacity (i.e. adding new runways) and ability to lengthen existing runways. The emergence of wide-body jets for international traffic prompted the need for a new airport in the region.

Transfer of traffic/Entry of carriers: All international activities (i.e. mostly using wide-body jets) were relocated to Taipei/Taoyuan after its opening in 1979[1].

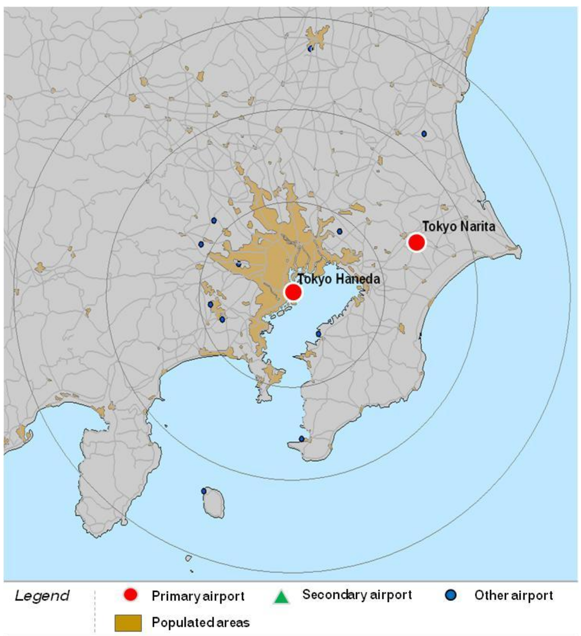
Congestion of primary airports: cf. Taipei/Songshan

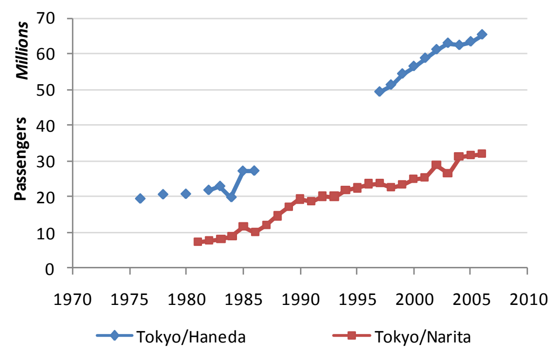
Limitations of existing airports: cf. Taipei/Songshan

[1] Source: Taipei Songshan Airport website, *"A Review: 50 Years of the Taipei Songshan Airport"*, available at; http://www.tsa.gov.tw/2005tax/english/e-50y.htm, last accessed; April 2008.

Appendix C-8: Asia/Pacific - Tokyo (Japan)

The multi-airport system that serves the metropolitan region of Tokyo is composed of two primary airports; Tokyo/Haneda (HND-RJTT) and Tokyo/Narita (NRT-RJAA). Tokyo/Haneda was the original airport in the metropolitan region and is currently used of domestic operations. Tokyo/Narita was opened in 1978 and gradually became a primary airport (mostly serving international traffic).





a. Tokyo/Haneda (HND): Original airport (primary)

Tokyo/Haneda is located 8 miles from the center of the city of Tokyo. It opened in 1931 and was returned to Japan by the United States in 1952[1]. The airport became mostly a domestic traffic airport after the opening of Tokyo/Narita in 1978.

Congestion of primary airports and limitations of existing airports: Tokyo/Haneda was becoming congested in the 1960s and its expansion was limited (i.e. large amounts of land would have needed to be reclaimed on the harbor). Despite the limitations that were identified, in the 1980s, the airport site was expanded using a site adjacent to the bay. This expansion of the airport footprint allowed the construction of a new runway in 1988.

[1] Source: Tokyo Haneda International Airport, company profile, available at http://www.tokyo-airport-bldg.co.jp/en/company/, last accessed; March 2008.

b. Tokyo/Narita (NRT): Primary airport emerged through the construction of a new airport

Tokyo/Narita is located 32 miles from the center of the city of Tokyo. It opened in 1978 and serves mostly international traffic.

Identification of a need to build a new airport: In the 1970s, the expansion of Tokyo/Haneda was impractical from a cost and technical standpoint. This prompted the need to build a second airport in the region. In 1962, alternatives to Tokyo/Haneda were being investigated.

Planning, Financing and Construction of new airport: The site was chosen in the early 1960s and the development was made public in 1966. The planning and development processes suffered from the conflict between the government and the local residents (cf. Role of regulatory and political factors). Initially, the airport was planned to be built by 1971. However, the conflict and opposition actions, delayed the opening of the airport to 1978[1].

Transfer of traffic/Entry of carriers: All international operations were transferred from Tokyo/Haneda to Tokyo/Narita when the airport opened in 1978.

Forecast of future passenger traffic within the metropolitan region: In the 1960s, Japan lifted travel restrictions on its citizens which resulted in increased demand for air transportation in the metropolitan region.

Congestion of primary airports: cf. Tokyo/Haneda
Limitations of existing airports: cf. Tokyo/Haneda

Role of regulatory and political factors: Conflict between population and government in the expansion of the project. In addition to local residents opposing the airport

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[1] Source: The Japan Times, 2005, *"Narita fiasco: never again"*, available at; http://search.japantimes.co.jp/print/opinion/ed2005/ed20050726a1.htm, last accessed; April 2008.

construction, the Japanese population was also opposed to it. Eminent domain power was used for the development of the airport and was violently opposed[1].

[1] Source: The Japan Times, 2005, *"Narita fiasco: never again",* available at; http://search.japantimes.co.jp/print/opinion/ed2005/ed20050726a1.htm, last accessed; April 2008.

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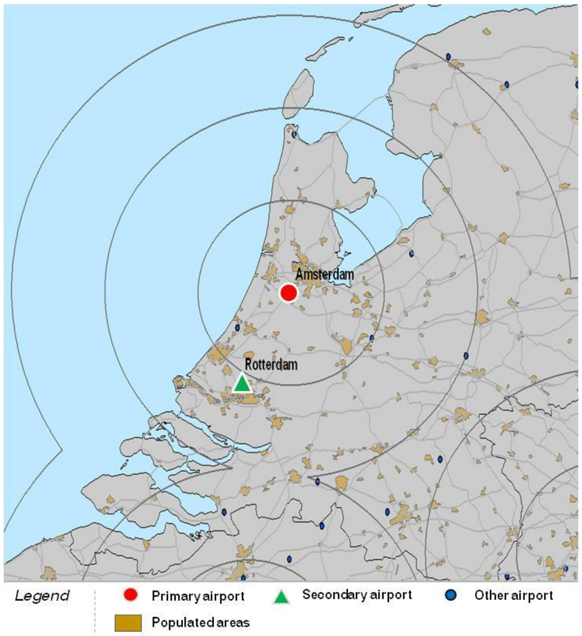
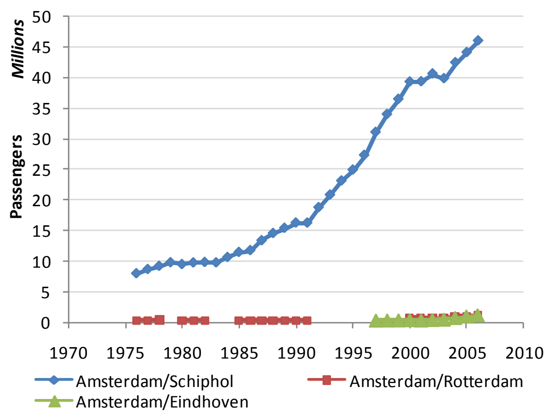
Appendix C-9: Europe - Amsterdam (Netherlands)

The multi-airport system that serves the Amsterdam region is composed of one primary airport; Amsterdam/Schiphol (AMS-EHAM) and two secondary airports; Amsterdam/Rotterdam (RTM-EHRD) and Amsterdam/Eindhoven (EIN-EHEH).





a. Amsterdam/Schiphol (AMS): Original airport (primary)

Amsterdam/Schiphol is located 7 miles from the center of the city of Amsterdam. It was built in 1916 and started commercial operations in 1920. It is the primary airport serving the Amsterdam metropolitan region[1].

Congestion of primary airports: According to the 2003, ACI/ATAG/IATA Airport Capacity Demand / Demand Profiles report[2], the runway and apron systems at Amsterdam/Schiphol were "near saturated at peak hours" in 2001. In addition, the capacity of the airport is limited by runway, apron and ATC considerations.

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[1] Source: Airport Technology, Industry Projects page; *"Schiphol Airport (AMS/EHAM), Amsterdam, Netherlands",* available at; http://www.airport-technology.com/projects/schiphol/, last accessed; April 2008.

[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

Expansion plans: Plans for a fifth runway were announced in 1970. The Dutch Parliament in 1995 gave approval to the project with the condition that the noise level in the airport environs did not increase. Construction of the fifth runway at started in September 2000 and became operational in 2003[1].

b. Amsterdam/Rotterdam (RTM): Emerged secondary airport

Amsterdam/Rotterdam is located 34 miles from the center of the city of Amsterdam. It was built in 1955 and was opened in 1956. The airport had limited traffic after the opening and could not attract traffic from Amsterdam/Schiphol. For almost thirty years the airport faced closure, but the economic growth in the 1990s caused an increase in passengers again and in 2001 it was decided that the airport's current location would be maintained for at least 100 years.

Entry of carriers (e.g. low-cost carriers): Transavia.com (i.e. low-cost carrier subsidiary of Air France/KLM), Fly VLM[2].

Upgrade of airport infrastructure: Runway renovation is underway in 2007/2008[3].

Presence of secondary basins of population: The airport is located close to the city of Rotterdam (i.e. population 584,046).

Congestion of primary airports: cf. Amsterdam/Schiphol

Role of ownership and management of airports: Rotterdam airport is also owned and operated by the Schiphol Group.

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[1] Source: Airport Technology, Industry Projects page; *"Schiphol Airport (AMS/EHAM), Amsterdam, Netherlands",* available at; http://www.airport-technology.com/projects/schiphol/, last accessed; April 2008.
[2] Source: Amsterdam/Rotterdam website; available at: http://www.rotterdam-airport.nl/, last accessed; March 2008.
[3] Rotterdam Airport website, available at; http://www.rotterdam-airport.nl/, last accessed; March 2008.

c. Amsterdam/Eindhoven (EIN): Emerged secondary airport

Amsterdam/Eindhoven is located 66 miles from the center of the city of Amsterdam. It was built in 1932[1].

Entry of carriers (e.g. low-cost carriers): Ryanair, Transavia.com (other scheduled airlines; KLM Cityhopper, Denim Airways, Airlinair, Iceland Express, Corendon Airlines)[2].

Changes of airport status; conversion from military to civil status: Amsterdam/Eindhoven is used for both civilian and military traffic (Welschap Air Base).

Upgrade of airport infrastructure: In 2000, a new terminal was completed. It has a capacity of 1.2 million passengers a year[3].

Presence of secondary basins of population: Amsterdam/Eindhoven is located close to the city of Eindhoven that had a population of 210,000 in 2008.

Congestion of primary airports: cf. Amsterdam/Schiphol

Role of ownership and management of airports: Amsterdam/Eindhoven is owned at 51% by the Schiphol Group. The objective of the Schiphol Group in developing Amsterdam/Eindhoven is to "contribute to the improvement of the accessibility of the surrounding region through the profitable and sustainable operation"[4].

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[1] Source: Amsterdam/Eindhoven website, available at: http://www.eindhovenairport.com/, last accessed; March 2008.

[2] Ibid.

[3] Ibid.

[4] Ibid.

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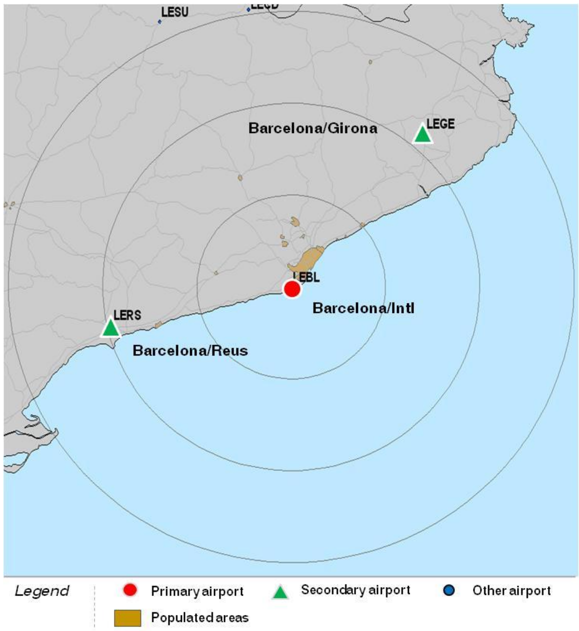
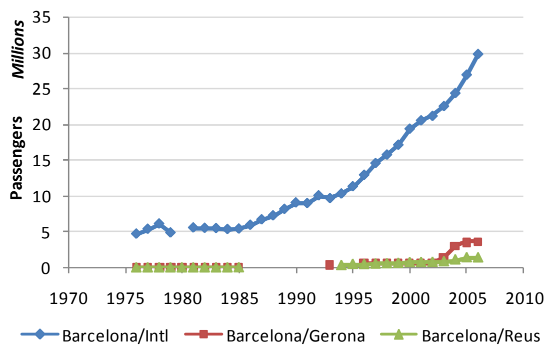
Appendix C-10: Europe - Barcelona (Spain)

The multi-airport system that serves the Barcelona region is composed of one primary airport; Barcelona/Intl (BCN-LEBL) and two secondary airports; Barcelona/Girona (GRO-LEGE) and Barcelona/Reus (REU-LERS).





a. Barcelona/Intl (BCN): Original airport (primary)

Barcelona/Intl is located 8 miles from the center of Barcelona city. It was built in 1918. Commercial service started in 1927. It has always been the primary airport in the region. Barcelona International Airport completed a major four year expansion program in 2005[1].

b. Barcelona/Girona (GRO): Emerged secondary airport

Barcelona/Girona is located 46 miles from the center of Barcelona. It was built in 1965 and opened in 1967. In the 1970s, the airport experienced a surge in passenger traffic, due particularly to summer charter flights. From 1978, scheduled flights were

[1] Source: Airport Technology, Industry Projects page; *"Barcelona International Airport (El Prat) (BCN/LEBL), Spain"*, available at; http://www.airport-technology.com/projects/barcelona/, last accessed; April 2008.

redirected to Barcelona and tourist flights to other Mediterranean destinations. This led to a decrease in traffic, especially after 1983, when passenger figures reached 830,000.[1]

Entry of carriers (e.g. low-cost carriers): Barcelona/Girona exhibited significant growth of traffic with the entry of Ryanair in 2004. Barcelona/Girona is also served by other major low-cost carriers; Wizz Air, Centralwings, Thomsonfly, Transavia.com and other carriers; BMI British Midland Airways, Cityflyer Express, FlyGlobespan, Iberia, Jetair Fly, Monarch Airlines My Travel Airways[2].

c. Barcelona/Reus (REU): Emerged secondary airport

Barcelona/Reus is located 55 miles from the center of Barcelona. It was built in 1935 and was used as a military base and flight training airport. In 1957, Barcelona/Reus opened to domestic air traffic, and the 1960s marked the beginning of charter flights[3].

Upgrade of airport infrastructure: In 1974, the passenger terminal was built. It was also enlarged and upgraded in 1979 and 1988[4].

Changes of airport status; conversion from military to civil status: In October 1998, the armed forces abandoned all of the military facilities on the airport grounds, except for a small aircraft apron. Since 1998, Barcelona/Reus has served civil aviation exclusively[5].

Entry of carriers (e.g. low-cost carriers): In 2004, with the commencement of low-cost airline operations (i.e. Ryanair), traffic levels grew significantly[6]. (Other airlines serving Barcelona/Reus include; Astraeus, British Midland Airways, First Choice Airways Futura

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[1] Source: Aeropuertos Espagnoles y Navigacion Aerea (AENA), Barcelona/Girona, History, available at: http://www.aena.es/, last accessed; March 2008.
[2] Source: Aeropuertos Espagnoles y Navigacion Aerea (AENA), available at: http://www.aena.es/, last accessed; March 2008.
[3] Source: Aeropuertos Espagnoles y Navigacion Aerea (AENA), Reus Airport, History, available at: http://www.aena.es/, last accessed; March 2008.
[4] Ibid.
[5] Ibid.
[6] Ibid.

Intenacional, Iberia Iberworld, Jetair Fly, LTE International Airways, Monarch Airlines My Travel Airways, Swiss International Air Lines, Thomsonfly).

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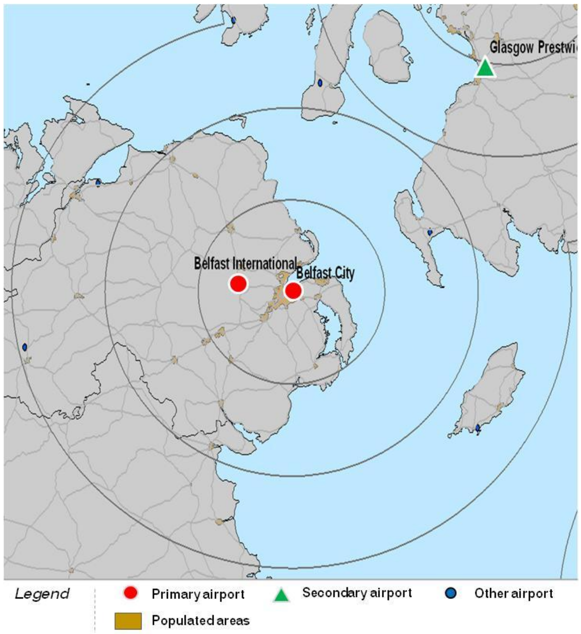
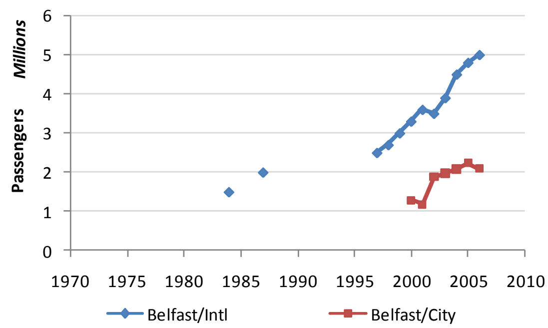
Appendix C-11: Europe - Belfast (United Kingdom)

The multi-airport system that serves the Belfast metropolitan region is composed of two primary airports; Belfast/City (BHD-EGAC) and Belfast/Intl (BFS-EGAA).





a. Belfast/Intl (BFS): Primary airport

Belfast/Intl is located 13 miles west of the center of Belfast. It was built in 1918. It was originally used as a military airfield (and remained a military bases during World War II). Commercial traffic started in 1933 and flights from Nutts Corner airport (i.e. Royal Air Force base) were transferred to Belfast/Intl in 1963.

Role of ownership and management of airports: The airport was privatized in 1994 (i.e. Belfast International Airport Holdings Ltd.) In 1996, TBI acquired Belfast/Intl (TBI was acquired by ACDL in 2005).

b. Belfast/City (BHD): Primary airport (originally a primary airport)

Belfast/City is located 3 miles from the center of the city of Belfast[1]. It was built in 1938 and was originally the primary airport in the region prior to 1946 when flights were transferred, in 1946, to a military airfield that had longer runways and could accommodate larger aircraft. The airport re-opened to civil traffic in 1983. Following major capital investment Bombardier (i.e. former owner of the airport) sold the airport to Ferrovial.

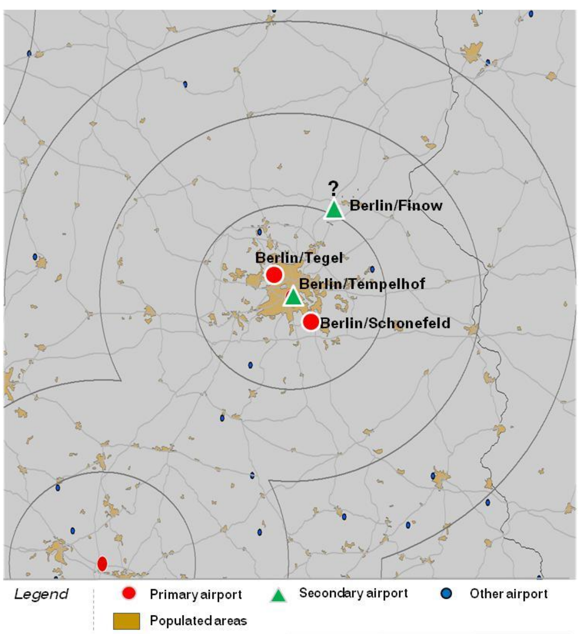
Role of ownership and management of airports: In 2003, ownership of Belfast/City was transferred from Bombardier to Ferrovial[2].

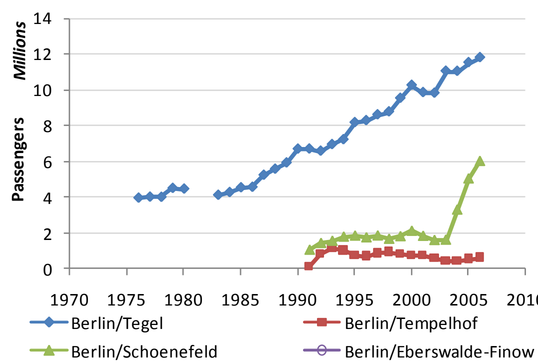
[1] Source: Airport Technology, Industry Projects page; *"George Best Belfast City Airport (BHD/EGAC), Northern Ireland, United Kingdom",* available at; http://www.airport-technology.com/projects/belfast/, last accessed; April 2008.

[2] Source: Airport Technology, Industry Projects page; *"George Best Belfast City Airport (BHD/EGAC), Northern Ireland, United Kingdom",* available at; http://www.airport-technology.com/projects/belfast/, last accessed; April 2008.

Appendix C-12: Europe - Berlin (Germany)

The multi-airport system that serves the metropolitan region of Berlin is composed of three primary airports; Berlin/Tegel (TXL-EDDT), Berlin/Tempelhof (THF-EDDI) and Berlin/Schoenefeld (SXF-EDDB). This airport system is in the process of consolidation. In 2008, Berlin/Schoenefeld should become the only primary airport in the metropolitan region. This consolidation process is expected to involve the closure of Berlin/Tegel, Berlin/Tempelhof in 2008 and 2011 respectively. In parallel to this consolidation process (which is an exception in the general evolution of multi-airport systems), this system may also exhibit the dynamic of emergence of a secondary airport with Berlin/Eberswalde-Finow.





a. Berlin/Tempelhof (THF): Original airport (secondary)

Berlin/Tempelhof is located 3 miles from the center of the city of Berlin. It was built in 1909. It was used as a military airport during WWII. It returned to civil use in 1951. The airport expected to close in 2008 after the upgrade of Berlin/Schoenefeld and transfer of traffic.

Limitations of the primary airport: In the 1970s, the runways at Berlin/Tempelhof were too short for accommodate jet aircraft. The airport is surrounded by urban development and expansion was not possible[1].

Role of ownership and management of airports: Berlin/Tempelhof, Berlin/Tegel and Berlin/Schoenefeld are owned and operated by one entity (i.e. Berlin Airports), which makes the consolidation and coordination process possible to perform.

b. Berlin/Tegel (TXL): Primary airport

Berlin/Tegel is located 5 miles from the center of the city of Berlin. It was built in 1930 and used as a military base during WWII. It returned to civil use in 1960. It replaced Berlin/Tempelhof in the 1970s. It is expected to close in 2011 after the upgrade of BBI and transfer of traffic.

Limitations of the primary airport: cf. Berlin/Tempelhof.

Role of ownership and management of airports: Berlin/Tempelhof, Berlin/Tegel and Berlin/Schoenefeld are owned and operated by one entity (i.e. Berlin Airports), which makes the consolidation and coordination process possible to perform.

c. Berlin/Schoenefeld (SXF): Primary airport

Berlin/Schoenefeld is located 11 from the center of the city of Berlin. It opened in 1934 and was used as a military base during WWII. It returned to civil use in 1954. After infrastructure upgrade, the airport will become the only primary airport in the region after the transfer of traffic from Berlin/Tegel and Berlin/Tempelhof in 2008[2].

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[1] Source: Airport Technology, Industry Projects page; *"Berlin-Brandenburg International Airport, Schönefeld, Germany",* available at; http://www.airport-technology.com/projects/berlin/, last accessed; April 2008.

[2] Source: Airport Technology, Industry Projects page; *"Berlin-Brandenburg International Airport, Schönefeld, Germany",* available at; http://www.airport-technology.com/projects/berlin/, last accessed; April 2008.

Congestion of primary airports: cf. Berlin/Tempelhof and Berlin/Tegel.

Expansion and development of the airport: The plans to expand Berlin/Schoenefeld were announced in 2000 but due to legal and financing problems the airport expansion was delayed. In March 2006 the Bundesverwaltungsegericht in Leipzig gave the go-ahead for the project by ruling in favor of Berlin-Brandenberg against challenges by residents and municipalities near the future airport. Berlin/Schoenefeld will be expanded by 970ha to a total area of 1,470ha[1].

Role of ownership and management of airports: Berlin/Tempelhof, Berlin/Tegel and Berlin/Schoenefeld are owned and operated by one entity (i.e. Berlin Airports), which makes the consolidation and coordination process easier to perform.

d. Berlin/Eberswalde-Finow (EDAV): Potential secondary airport

Despite consolidation process taking place with the Berlin/Tempelhof, Berlin/Tegel and Berlin/Schoenefeld, that would transform this multi-airport system into a single airport system, a secondary airport, Berlin/Eberswalde-Finow, could emerge in the region.

Changes of airport status; conversion from military to civil status: Berlin/Eberswalde-Finow opened in 1938 and was used as a military basis until 1993.

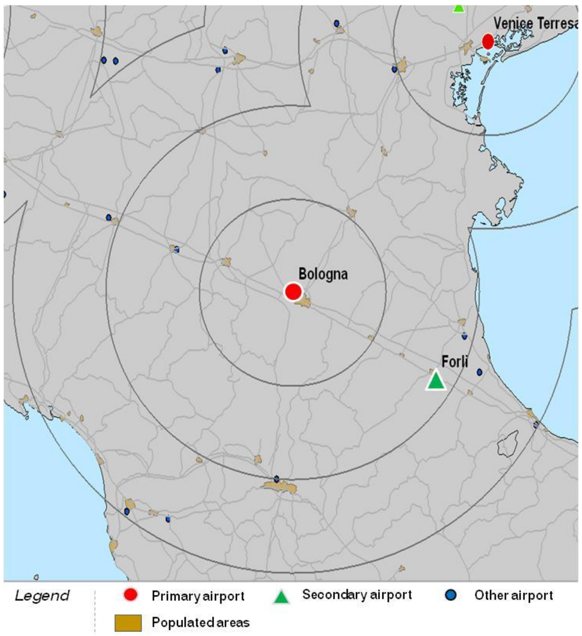
Role of ownership and management of airports: In 2003, Infratil (a New Zealand private infrastructure investment group) entered into a 10 year option to purchase Berlin/Eberswalde-Finow. A plan to develop Berlin/Eberswalde-Finow into a secondary airport was established (long-term investment program of approx. €25 million). The case of the Berlin airport system combines some aspects of both the Frankfurt system (centralized and controlled development process) and the Johannesburg dynamics (i.e.

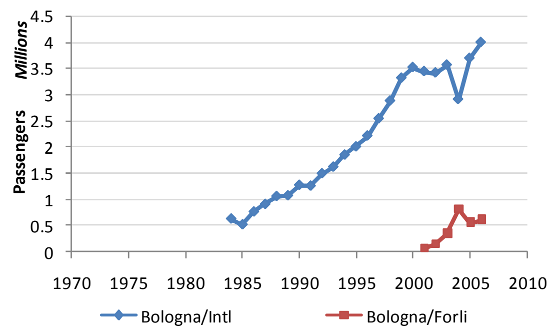
[1] Source: Airport Technology, Industry Projects page; *"Berlin-Brandenburg International Airport, Schönefeld, Germany",* available at; http://www.airport-technology.com/projects/berlin/, last accessed; April 2008.

independent and decentralized potential privatization of an under-utilized airport that could emerge into a secondary airport). Berlin/Eberswalde-Finow is a case of the use of real options, where Infratil placed an option to purchase the airport by 2013 (the value of this airport being dependent on the evolution of other airports in the region and more specifically the close of both Berlin/Tegel and Berlin/Tempelhof).

Appendix C-13: Europe - Bologna (Italy)

The multi-airport system that serves the region of Bologna is composed of one primary airport; Bologna/Intl (BLQ-LIPE) and one secondary airport; Bologna/Forli (FRL-LIPK).





a. Bologna/Intl (BLQ): Original airport (primary)

Bologna/Intl is located 4 miles from the center of the city of Bologna. It has historically been the primary airport serving the region.

b. Bologna/Forli (FRL): Emerged secondary airport

Entry of carriers (e.g. low-cost carriers): Ryanair started to offer scheduled service at Bologna/Forli in 2002. Bologna/Forli now serves; Wind Jet, South Airlines, Ryanair, Ukraine International, Belle Air, Cimber Air[1].

Presence of secondary basins of population: Bologna/Forli is located 2.2 miles from the city of Forli (population of 112,477).

[1] Source: Bologna/Forli website, available at: http://www.forliairport.com/, last accessed; March 2008.

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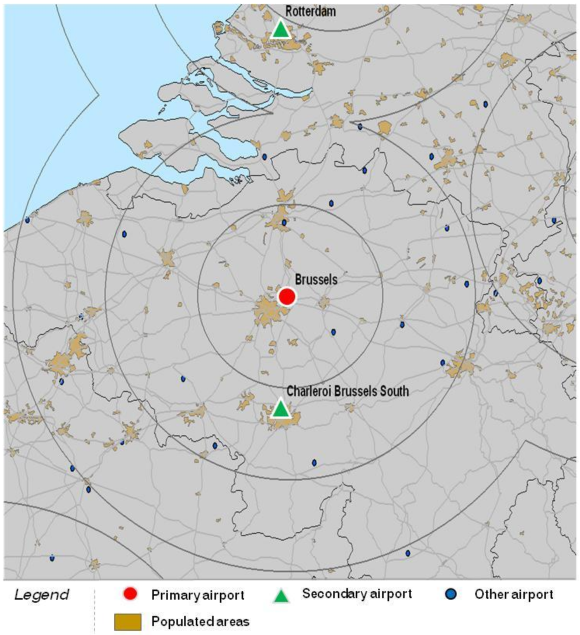
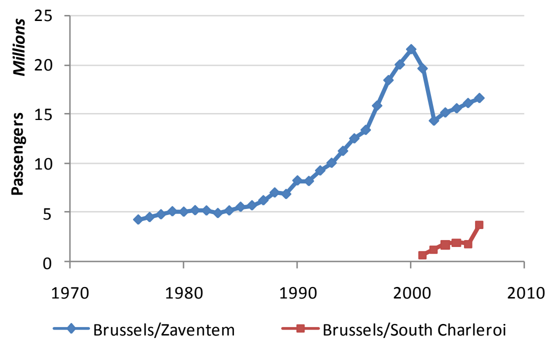
Appendix C-14: Europe - Brussels (Belgium)

The multi-airport system serving the Brussels region is composed of one primary airport; Brussels/Zaventem (BRU - EBBR) and one secondary airport; Brussels/South Charleroi (CRL - EBCI).





a. Brussels/Zaventem (BRU): Original airport (primary)

Brussels/Zaventem was constructed in 1956. In the 1950s, Brussels/Melsbroek was gradually becoming too small and did not have the capacity to accommodate projected number of tourists for the 1958 World Exhibition[1]. Since 1956, Brussels/Zaventem is the primary airport serving the Brussels' metropolitan region.

In 2006, the airport handled 16.6 million passengers after a period of slow growth (i.e. average annual of 3.7% between 2002 and 2006). In 2002, the bankruptcy of Sabena in 2001 (based in Brussels/Zaventem) resulted in a sharp decline of traffic.

[1] Source: Brussels Airport, *"Airport history'*, available at: http://www.brusselsairport.be/en/about-airport/airport-history, last accessed; April 2008.

Congestion of primary airports: According to the 2003, Airport Capacity Demand / Demand Profiles report[1], the runway and apron at Brussels/Zaventem were "near saturated at peak hours" in 2001 (before the demise of Sabena).

b. Brussels/South Charleroi (CRL): Emerged secondary airport

Brussels/South Charleroi located 26 miles south of the city of Brussels. It was built in 1919 and used a military airfield during World War II. The airport was converted to civil use after the war and emerged as a secondary airport in the 1990s with the entry of low-cost carriers.

Entry of carriers (e.g. low-cost carriers): Brussels/South Charleroi emerged as a secondary airport with the entry of Ryanair (i.e. low-cost carrier) in 1997. Before the entry of Ryanair, the airport handled 20,000 passengers[2]. Since 1997, traffic continuously increased (i.e. traffic reached 2.2 million passengers in 2006). Following the entry of Ryanair, other low-cost carriers have followed (e.g. Wizzair, OnAir, Jet4You.com).

Changes of airport status; conversion from military to civil status: Brussels/South Charleroi was transferred to civil use after World War II.

Upgrade of airport infrastructure: As of 2008, several airport enhancement projects were scheduled; the transition to Cat. III ILS, the extension of the current runway from 2,550 m to 3,200m, and the expansion of ground access by shuttle busses between the airport and the main Belgian cities, the north of France and the Grand Duchy of Luxembourg[3].

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[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[2] Source: European Commission (2004) Commission decision on 12 February 2004. Official Journal of the European Union, April 30th 2004.

[3] Source: Brussels/South Charleroi website, available at: http://www.charleroi-airport.com, last accessed; March 2008.

Congestion of primary airports: cf. Brussels/Zaventem. After the demise of Sabena[1] in 2001 and the resulting sharp drop in operations, congestion was eased at Brussels/Zaventem.

Provision of airline entry incentives: The case of Brussels/South Charleroi is a typical case of provision of airline entry incentives (i.e. to Ryanair). In 2001, the government of Wallonia, which owns Brussels/South Charleroi, provided financial incentives to Ryanair in the form of reduced landing charges, reduced ground handling service charges, and support for the opening of Ryanair's base[2]. According to a 2004 report from the European Commission, under the proposed reduced charges agreement between the government of Wallonia and Ryanair, the landing fee and the handling charges were reduced by 50% and 90% respectively. In February 2004, the European Commission concluded that the agreement of reduced in charges was not compliant with article 87 of the Treaty. It was found that the reduced charges were incompatible with the common market and created distortion of the competition environment (e.g. with airlines operating at other airports in the region such as Brussels/Zaventem (BRU))[3].

Role of ownership and management of airports: Brussels/South Charleroi is owned by the Government of Wallonia and operated by Brussels International Airport Company. In the case of the combination of Brussels/Zaventem and Brussels/South Charleroi that are not owned and operated by the same authorities (i.e. unlike airport systems such as Frankfurt/Main and Frankfurt/Hahn), the strategic development of both airports is not centralized (i.e. in 2009, Brussels/Zaventem is expected to receive a new low-cost terminal, to attract low-cost carriers and compete with Brussels/South Charleroi). In the case of the Frankfurt multi-airport system, the products (i.e. airport service offerings) are differentiated by airports, with the primary airport serving legacy and network carriers and the secondary airport specialized in low-cost services.

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[1] Source: Brussels Airport, *"Airport history',* available at: http://www.brusselsairport.be/en/about-airport/airport-history, last accessed; April 2008.

[2] Source: Barbot, C., (2004), *"Low cost carriers, secondary airports and state aid: an economic assessment of the Charleroi affair"*, CETE – Centro de Estudos de Economica Indsutrial, do Trabalho e da Empresa, Universidade do Porto, Porto, Portugal.

[3] Ibid.

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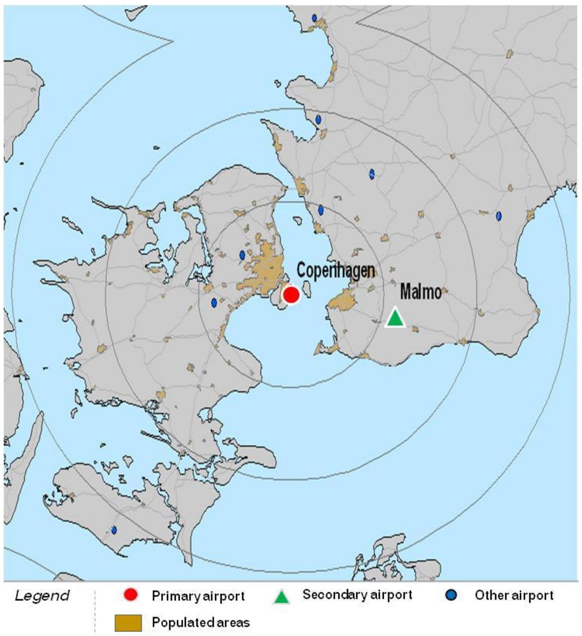
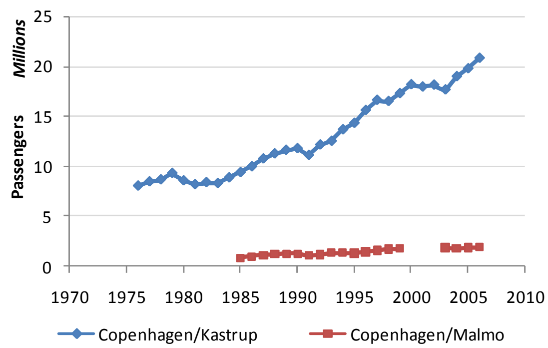
Appendix C-15: Europe - Copenhagen (Denmark)

The multi-airport system that serves the metropolitan region of Copenhagen is composed of one primary airport; Copenhagen/Kastrup (CPH-EKCH) and one secondary airport; Copenhagen/Malmo (MMX-ESMS).





a. Copenhagen/Kastrup (CPH): Original airport (primary)

Copenhagen/Kastrup is located 6 miles from the center of the city of Copenhagen. It was built in 1925 and has historically been the primary airport serving the region[1].

Congestion of primary airports: In the 1970s, the airport suffered from acute space shortages, especially with the emergence of wide-body jet aircraft. The planning process of the construction of a new airport in Saltholm (i.e. island located in the strait that separates Denmark and Sweden), was abandoned due to local opposition and blockage from Denmark's parliament in 1979[2]. According to the 2003, Airport Capacity Demand /

[1] Source: Copenhagen Airport, *"Airport History"*, available at: http://www.cph.dk/CPH/UK/ABOUT+CPH/History/, last accessed; April 2008.
[2] Ibid.

Demand Profiles report[1], the runway and apron of Copenhagen/Kastrup were "near saturated at peak hours" in 2001 (with no development reported to alleviate the problem).

b. Copenhagen/Malmo (MMX): Emerged secondary airport (Second phase)

Copenhagen/Malmo is located 34 miles from the center of Copenhagen. It was built in 1972. Copenhagen/Malmo replaced the Bulltofta Airport (i.e. original airport serving the region since 1923). The expansion of this latter airport was constrained by urban development and limitations on runway length.

Entry of carriers (e.g. low-cost carriers): Ryanair started offering service at Copenhagen/Malmo in 1998. However, Ryanair closed all its routes from Copenhagen/Malmo in 2007. Sterling Airlines, another low-cost carrier, followed the entry of Ryanair[2].

Presence of secondary basins of population: Copenhagen/Malmo is located 17 miles from the center of the city of Malmo (i.e. population; 280,000 for the city and 605,000 for the metropolitan area).

Congestion of primary airports: cf. Copenhagen airport

Provision of airline entry incentives: LFV Group, that manages Copenhagen/Malmo, has an active airline entry (i.e. new route) incentive provision program. Discount on new destinations are provided to stimulate traffic growth through discounts on take-off and terminal navigation charges and discount on passenger charges (excluding security charges) for a five year period.

Role of ownership and management of airports: The airport is operated by LFV Group.

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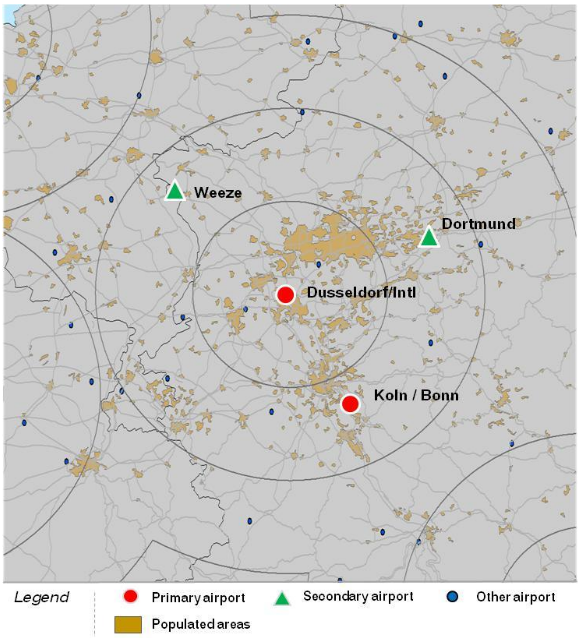
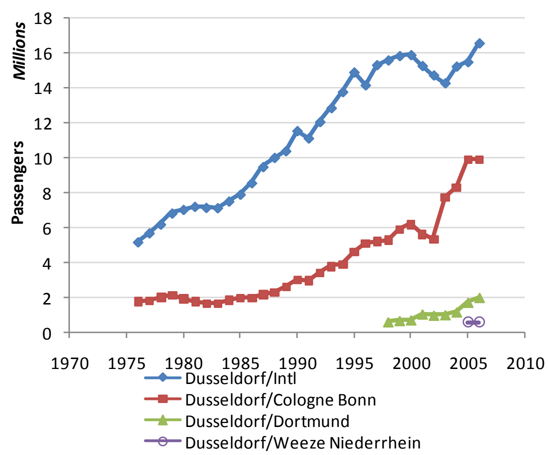
[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[2] Source: LFV website, Malmo airport information, available at; http://www.lfv.se/, last accessed; April 2008.

Appendix C-16: Europe - Dusseldorf (Germany)

The multi-airport system that serves the Dusseldorf region is composed of two primary airports; Dusseldorf/Intl (DUS-EDDL) and Dusseldorf/Cologne Bonn (CGN-EDDK) and two secondary airports; Dusseldorf/Dortmund (DTM-EDLW) and Dusseldorf/Weeze Niederrhein (NRN-EDLV).





a. Dusseldorf/Intl (DUS): Original airport (primary)

Dusseldorf/Intl is located 4 miles from the center of the city of Dusseldorf[1]. It opened in 1927 and has historically always been the primary airport serving this metropolitan region.

Congestion of primary airports: According to the 2003, ACI/IATA/ATAG Airport Capacity Demand / Demand Profiles report[2], the runway and apron of Dusseldorf/Intl were "near saturated at peak hours" in 2001. In 2001, the average delay per operation was 35.6 minutes. In addition, no runway and apron capacity improvements were scheduled.

[1] Source: Dusseldorf International website, available at; http://www.dus-int.de/, last accessed; April 2008.
[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

b. Dusseldorf/Cologne Bonn (CGN): Original airport (primary)

Dusseldorf/Cologne Bonn airport is located 29 miles from the center of Dusseldorf. It was built in 1938, and used as a military airport during World War II. It was then returned to civil operations in 1951. The airport was expanded during the 1980s and 1990s[1].

Entry of carriers (e.g. low-cost carriers): Due to available capacity that was developed in the 1980s and 1990s, and limitations of Dusseldorf/Intl, the airport was attractive for low-cost carriers (e.g. Germanwings and TUIfly in 2002, easyJet in 2003 and Wizzair in 2006)[2].

c. Dusseldorf/Dortmund (DTM): Emerged secondary airport

Dusseldorf/Dortmund is located 40 miles east of the city of Dusseldorf. It was built in 1926 and used as military air base during World War II[3].

Entry of carriers (e.g. low-cost carriers): Entry of Air Berlin in 2002 (not operating in 2007), Easy Jet in 2004 and Germanwings in 2007.

Changes of airport status; conversion from military to civil status: The airport was returned to civil use in 1955 but commercial traffic was restored in 1979.

Presence of secondary basins of population: The airport is located close to the city of Dortmund (i.e. population of 585,045 in 2008).

Congestion of primary airports: cf. Dusseldorf/Intl

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[1] Source: Cologne Bonn Airport website, Press Office, History, available at; http://www.airport-cgn.de/main.php?id=140&lang=2, last accessed; April 2008

[2] Source: Cologne Bonn Airport website, available at; http://www.airport-cgn.de/, last accessed; April 2008

[3] Source: Dortmund Airport website, history, available at; http://flughafen-dortmund.de/index.php?id=70&L=1, last accessed; March 2008

d. Dusseldorf/Weeze Niederrhein (NRN): Emerged secondary airport

Dusseldorf/Weeze Niederrhein is located 37 miles from the center of Dusseldorf. It was built in 1954 and used as military air base. It opened to civil activities in 2003[1].

Entry of carriers (e.g. low-cost carriers): In 2003, Ryanair started offering scheduled service at Dusseldorf/Weeze Niederrhein. Sky Airlines (2004), Hamburg International (2005) followed Ryanair's entry.

Changes of airport status; conversion from military to civil status: Dusseldorf/Weeze Niederrhein airport was originally a Royal Air Force base (i.e. RAF Laarbruch) and was the base of several squadrons. After closing in 1999 the airfield was transformed into a civil airfield. Civil operations began in May 2003 with the entry of Ryanair[2].

Upgrade of airport infrastructure: In 2003, a new passenger terminal and new aprons are performed.

Congestion of primary airports: cf. Dusseldorf/Intl

Role of ownership and management of airports: In 2001, a Dutch group of investors purchases Laarbruch base and transforms the airport into a secondary airport of Dusseldorf. Transport Minister E. Schwanhold granted the aviation law approval for civilian air traffic in June 2001.

[1] Source: Weeze Airport website, *"History of Airport Weeze"*, available at; http://www.airport-weeze.de/5-1-1_geschichte.php?lang=en, last accessed; April 2008

[2] Ibid.

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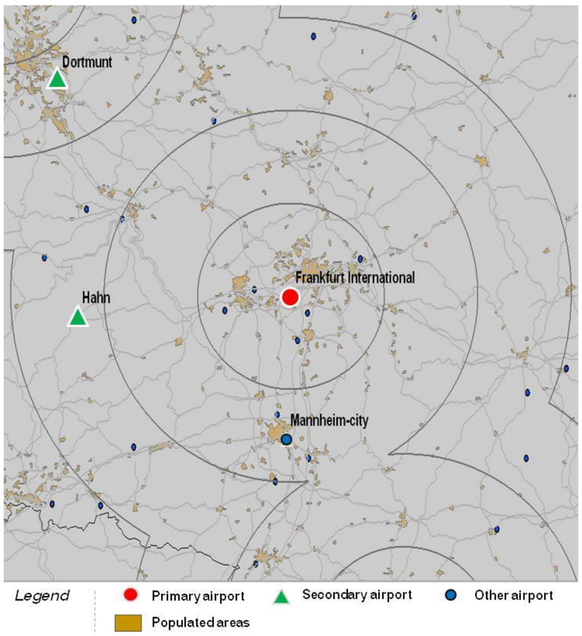
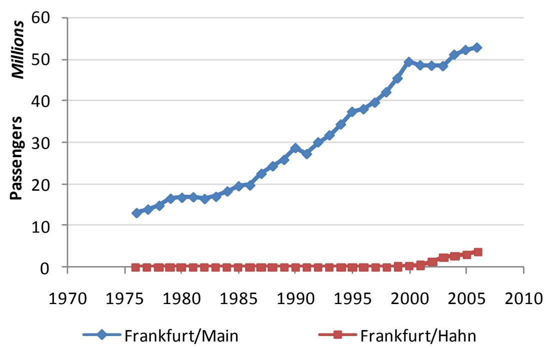
Appendix C-17: Europe - Frankfurt (Germany)

The multi-airport system that serves the Frankfurt metropolitan region is composed of one primary airport; Frankfurt/Main (FRA-EDDF) and one secondary airport Frankfurt/Hahn (HHN-EDFH).





a. Frankfurt/Main (FRA): Original airport (primary)

Historically, Frankfurt/Main has been the sole airport in the region, and has exhibited significant growth of traffic mostly due to its role as a hub for Lufthansa.

Congestion of the primary airport: In the 1990s the need to add capacity at the airport was apparent and a plan to expand Frankfurt/Main through the addition of a fourth runway was set. However, the project was delayed several times due to environmental constraints in particular due to a mediation process that was engaged in 1999. The airport is now scheduled to receive this fourth runway in 2010[1].

Role of ownership and management of airports: Frankfurt/Main is operated by an independent airport authority, which is fully owned by regional government with

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[1] Source: Fraport website, *"Information on Airport Expansion"*, available at: http://www.ausbau.fraport.com/cms/default/rubrik/2/2227.htm, last accessed; April 2008.

minority private shareholders; Fraport. Frankfurt/Hahn is also operated by Fraport (cf. Frankfurt/Hahn airport case study).

b. Frankfurt/Hahn (HHN): Emerged secondary airport

In parallel to the history of capacity expansion at Frankfurt/Main, a secondary airport Frankfurt/Hahn was developed and emerged at the end of the 1990s[1].

Congestion of the primary airport: cf. Frankfurt/Main.

Entry of carriers (e.g. low-cost carriers): Frankfurt/Hahn successfully attracted low-cost carriers, such as Ryanair that started to offer scheduled service in 1999. Wizzair also followed the entry of Ryanair[2].

Changes of airport status; conversion from military to civil status: This airport was constructed in 1947 as a NATO military base, and was opened to civil traffic in 1993.

Upgrade of airport infrastructure: Fraport expanded the capacity of Frankfurt/Hahn (e.g. terminal in 2005, runway extension in 2007).

Role of ownership and management of airports: Frankfurt/Hahn is operated by an independent Airport Authority, which is fully owned by regional government but with minority private shareholders (E), i.e. Fraport. The case of Frankfurt/Main system is an illustration of a successful development of multi-airport systems for which a centralized development process (one developer/operator) resulted in a controlled product differentiation; high cost hub airport and low-cost secondary airport to serve both legacy network carriers and low-cost carriers.

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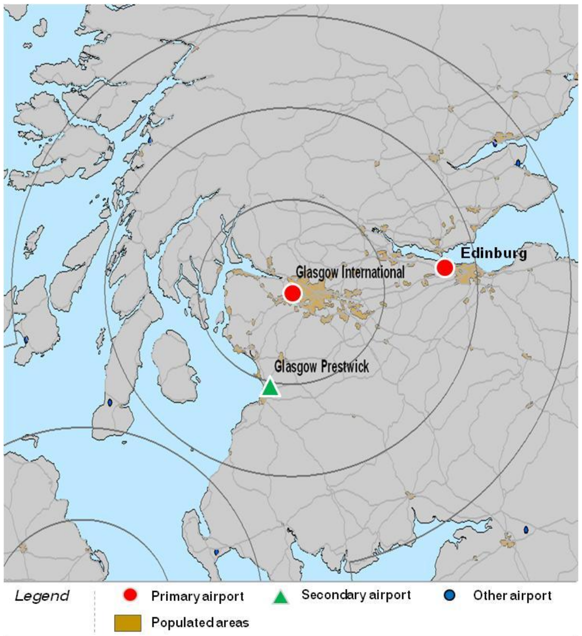
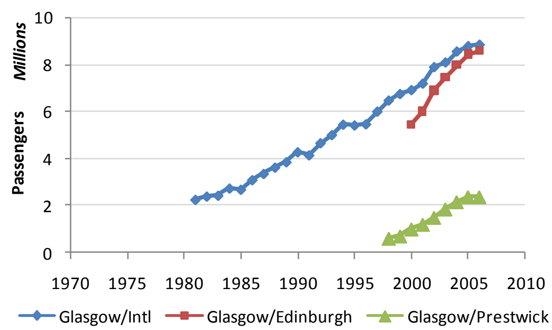
[1] Source: Frankfurt/Hahn airport website, available at: http://www.hahn-airport.de/, last accessed; April 2008.
[2] Ibid.

Appendix C-18: Europe - Glasgow (United Kingdom)

The multi-airport system serving the Glasgow metropolitan region is composed of two primary airports; Glasgow/Intl (GLA-EGPF) and Glasgow/Edinburgh (EDI-EGPH) and one secondary airport; Glasgow/Prestwick (PIK-EGPK).





a. Glasgow/Intl (GLA): Primary airport

Glasgow/Intl is located 15 miles from the center of Glasgow. It was built in 1932 and used as a military base until 1963. Commercial traffic in the region was served at an airport that was located 3 miles east of Glasgow/Intl. Traffic was transferred to Glasgow/Intl in the 1966. In the 1970s international flights were handled at Glasgow/Prestwick located south of Glasgow and Glasgow/Intl was handling domestic and intra-European traffic[1].

Role of ownership and management of airports: In 1975, the British Airports Authority (BAA) took ownership of Glasgow/Intl. Following the privatization of BAA in the late 1980s, Glasgow/Prestwick was sold (1991). As a result, the restrictions on Glasgow/Intl

[1] Source: Airport Technology, Industry Projects page; *"Glasgow Airport Skyhub Project, Scotland, United Kingdom",* available at; http://www.airport-technology.com/projects/skyhub/, last accessed; April 2008.

were lifted. International flights were transferred to Glasgow/Intl which became the main primary airport in the region.

b. Glasgow/Edinburgh (EDI): Original airport (primary)

Edinburg is located 34 miles from the center of the city of Glasgow. It was built in 1915 and re-opened to civil use in 1947. It serves as an international and domestic airport.

c. Glasgow/Prestwick (PIK): Emerged secondary airport

Glasgow/Prestwick is located 27 miles from the center of the city of Glasgow. It was built in 1934 and opened to civil use in 1938. The airport was used for international flights serving the Glasgow region until the end of the 1980s[1].

Entry of carriers (e.g. low-cost carriers): Ryanair started offering scheduled service at Glasgow/Prestwick in 1994.

Changes of airport status; conversion from military to civil status: The airport was used as a US Air Force based from 1952 until 1966.

Upgrade of airport infrastructure: In April 2005, Infratil completed a major airport improvement project (i.e. new terminal building) to accommodate growing traffic at Glasgow/Prestwick.

Presence of secondary basins of population: In addition, approximately two million people live within a one hour drive of Glasgow/Prestwick and four million within two hours[2].

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[1] Source: Glasgow Prestwick Airport website,*" Airport History"*, available at: http://www.gpia.co.uk/AirportInfo/history.asp, last accessed; April 2008.
[2] Source: Infratil, available at: http://www.infratil.com/, last accessed; March 2008.

Provision of airline entry incentives: *"Glasgow Prestwick Airport's aeronautical charges are also a factor in its favor, currently being well below the landing charges of BAA Glasgow Abbotsinch and Edinburgh"*[1].

Role of ownership and management of airports: The airport was sold by BAA to Infratil (i.e. a New Zealand investment group) in 1991. Infratil has performed infrastructure several improvements at Glasgow/Prestwick following its acquisition.

[1] Ibid.

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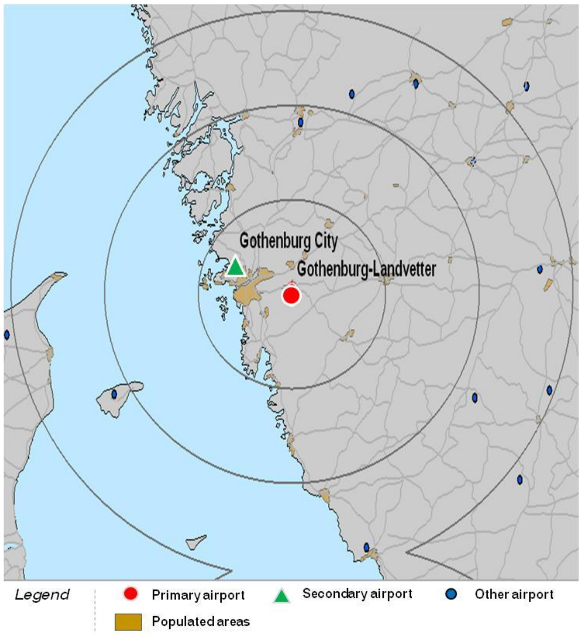
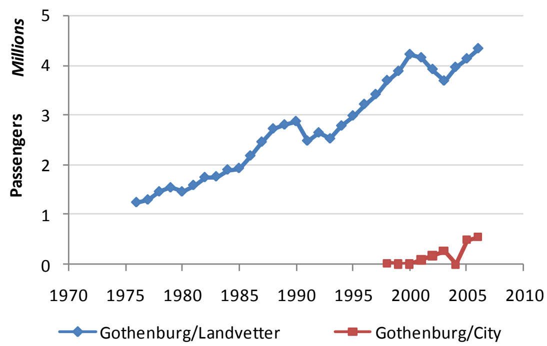
Appendix C-19: Europe - Gothenburg (Sweden)

The multi-airport system that serves the metropolitan region of Gothenburg is composed of one primary airport; Gothenburg/Landvetter (GOT-ESGG) and one secondary airport; Gothenburg/City (GSE-ESGP).





a. Gothenburg/Torslanda; Closed primary airport

Gothenburg/Torslanda was located north of the city of Gothenburg. It was the primary airport in the region until its closure in 1977.

Congestion of primary airports and limitations of existing airports: Gothenburg/Torslanda was constrained by its footprint and expansion was needed to accommodate larger aircraft in the 1970s.

b. Gothenburg/Landvetter (GOT): Original airport (primary)

Gothenburg/Landvetter is located 11 miles from the center of the city of Gothenburg. It was built in 1977[1]

[1] Source: LFV, Gothenburg/Landvetter history, available at: http://www.lfv.se/, last accessed; March 2008.

Phase I: Construction in response to constraints at Gothenburg/Torslanda

Identification of a need to build a new airport: cf. Gothenburg/Torslanda

Planning, Financing and Construction of new airport: In 1972, the land on which the airport was to be built was selected and was prepared for construction. Construction of buildings began in 1975. The airport opened in 1977[1].

Transfer of traffic/Entry of carriers: Flights were transferred from Gothenburg/Torslanda to Gothenburg/Landvetter in 1977.

Congestion of primary airports and limitations of existing airports: cf. Gothenburg/Torslanda

Phase II: Current status and constraints motivating the emergence of Gothenburg/City

Congestion of primary airports: According to the 2003, Airport Capacity Demand / Demand Profiles report[2], the runway and apron of Gothenburg/ Landvetter airport were "near saturated at peak hours" in 2001.

c. Gothenburg/City (GSE): Emerged secondary airport

Gothenburg/City is located 7 miles from the center of the city of Gothenburg. It was built as a military airbase in 1940 (i.e. Saeve). The airbase was closed down in 1969.

Entry of carriers (e.g. low-cost carriers): Ryanair started offering scheduled service from Gothenburg in 2001. Following the entry of Ryanair, two other low-cost carriers WizzAir and Air Berlin started offering service at Gothenburg/City[3].

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[1] Source: LFV, Gothenburg/Landvetter history, available at: http://www.lfv.se/, last accessed; March 2008.

[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[3] Source: Gothenburg/City website; available at: http://www.goteborgairport.se/, last accessed; March 2008.

Changes of airport status; conversion from military to civil status: The airport was built as a military airbase in 1940 (i.e. Saeve AB) which closed in 1969[1].

Upgrade of airport infrastructure: In 1984, the runway was improved and extended to allow larger business jets etc.

Presence of secondary basins of population: Due to its key location, Gothenburg/City serves directly the primary basin of population in the metropolitan region.

Congestion of primary airports: cf. Gothenburg/Landvetter

[1] Source: Gothenburg/City website; available at: http://www.goteborgairport.se/, last accessed; March 2008.

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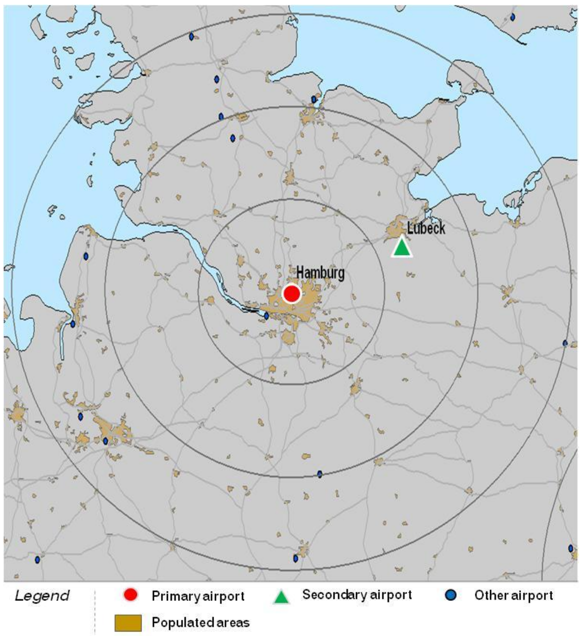
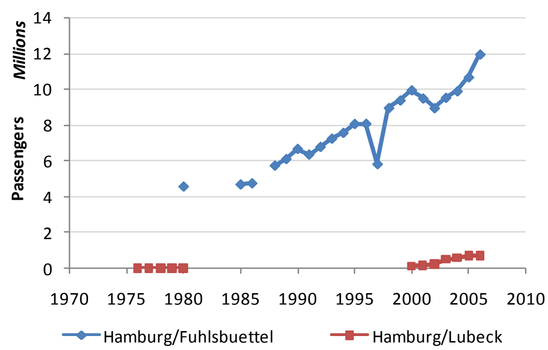
Appendix C-20: Europe - Hamburg (Germany)

The multi-airport system that serves the region of Hamburg is composed of one primary airport; Hamburg/Fuhlsbuettel (HAM-EDDH) and one secondary airport; Hamburg/Lubeck (LBC-EDHL).





a. Hamburg/Fuhlsbuettel (HAM): Original airport (primary)

Hamburg/Fuhlsbuettel is located 5 miles from the center of the city of Hamburg. It was built and opened in 1911. The airport has historically been the only primary airport in the metropolitan region[1].

b. Hamburg/Lubeck (LBC): Emerged secondary airport

Hamburg/Lubeck is located 34 miles from the center of the city of Hamburg and 6 miles from the city of Lubeck. It was built in 1917[2].

Changes of airport status; conversion from military to civil status: Hamburg/Lubeck is a former Royal Air Force (RAF) base (i.e. RAF Blankensee).

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[1] Source: Hamburg Airport website, *"About the airport – History",* available at: http://www.ham.airport.de/en/historie.html, last accessed; April 2008.

[2] Source: Lubeck Airport website, available at: http://www.flughafen-luebeck.net/Lubeck_en/, last accessed; April 2008.

Entry of carriers (e.g. low-cost carriers): Passenger traffic significantly increases after the entry of Ryanair in 2005. The airport is marketed as "Hamburg Lübeck"[1] by Ryanair[2]. Other low-cost carriers have followed the entry of Ryanair. In 2006, Wizzair opened routes to Gdansk in Poland. Jet2.com also operates scheduled services from Hamburg/Lubeck.

Upgrade of airport infrastructure: Due to an adverse court ruling on the project of extension of the runway (from 1,800 to 2,324 meters), the agreement with Ryanair to establish a base at Hamburg/Lubeck was cancelled in 2005[3].

Presence of secondary basins of population: Hamburg/Lubeck is located 5 miles northwest of the city of Lubeck, which is a secondary basin of population in the greater Hamburg metropolitan region. Lubeck had a population of 213,983 in 2005. The city is located in the district of Schleswig-Holstein, located east of Hamburg and has a population of 2,837,021 in 2007[4]). A regional economic study performed by the Lubeck Airport identified a basin of population of 4.1 million residents within a 90 minutes driving time of the airport[5].

Role of ownership and management of airports: In 2005, Infratil (a New Zealand based infrastructure investment company) acquired 90% of Flughafen Lübeck GmbH from the City of Lübeck. The city of Lubeck still owns 10% of the company's shares. The acquisition was authorized by the local authority supervisory body (i.e. Kommunalaufsicht Schleswig Holstein) after a revision of the agreement to extend the runway.

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[1] Source: Infratil, available at: http://www.infratil.com/, last accessed: March 2008.

[2] Source: Ryanair website, *"Destinations"*, available at: http://www.ryanair.com/site/EN/dests.php?loc=LBC, last accessed; April 2008.

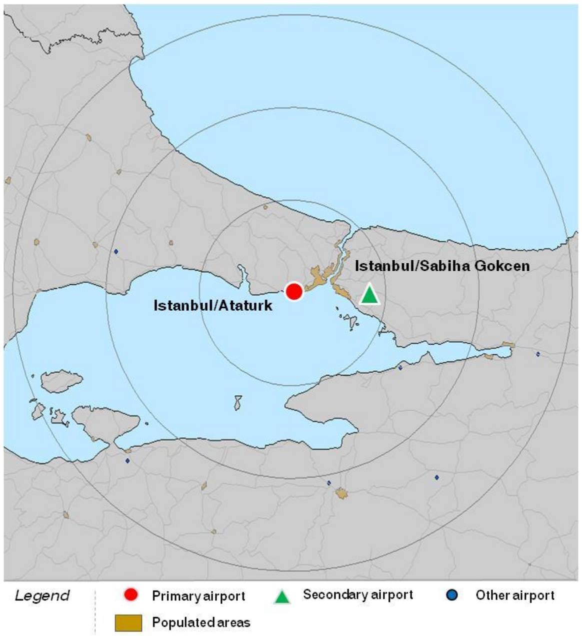
[3] Ibid.

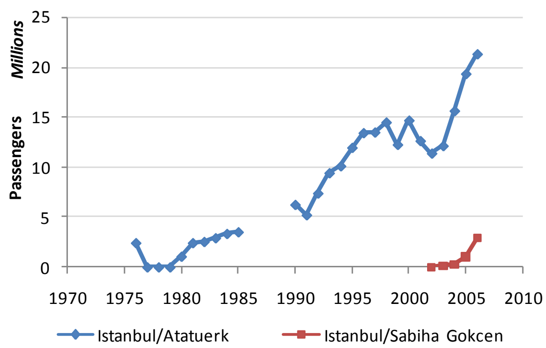
[4] Source: Portal of the Federal Statistics Office Germany, available at: www.statistik-portal.de, last accessed: March 2008.

[5] Source: Lubeck Airport website, available at: http://www.flughafen-luebeck.net/Lubeck_en/, last accessed; April 2008.

Appendix C-21: Europe - Istanbul (Turkey)

The multi-airport system that serves the region of Istanbul is composed of one primary airport; Istanbul/Atatuerk (IST-LTBA) and one secondary airport; Istanbul/Sabiha Gokcen (SAW-LTFJ).





a. Istanbul/Atatuerk (IST): Original airport (primary)

Istanbul/Atatuerk is located 9 miles west of Istanbul. It has historically been the primary airport in the region.

Congestion of primary airports: Istanbul/Atatuerk faces capacity constraints.

b. Istanbul/Sabiha Gokcen (SAW): Construction of a new airport

Istanbul/Sabiha Gokcen is located 9 miles from the center of Istanbul. It was built in 2000 and now serves domestic and international traffic in the metropolitan region.

Identification of a need to build a new airport: Demand growth in the region and the need to serve the Asian side of the city motivated the construction of Istanbul/Sabiha Gokcen.

Planning, financing and construction of new airport: The construction of Istanbul/Sabiha Gokcen started in 1998 and was completed in 2000.

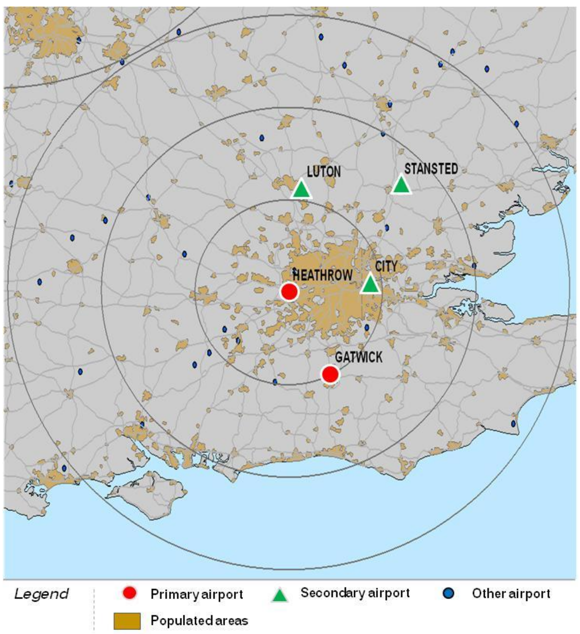
Transfer of traffic/Entry of carriers: Istanbul/Atatuerk remains utilized

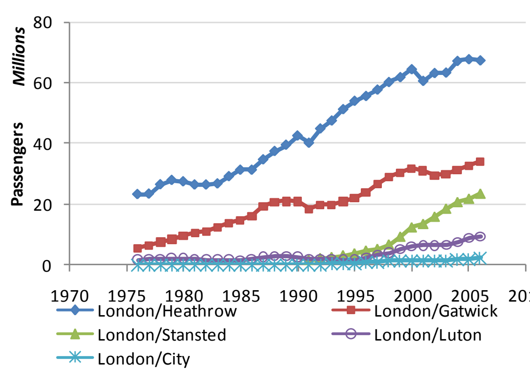
Congestion of primary airports and limitations of existing airports: cf. Istanbul/Atatuerk

Role of ownership and management of airports: The airport was built and is managed by a private company, HEAS and regulated by DHMI (State Airports Authority).

Appendix C-22: Europe - London (United Kingdom)

The multi-airport system that serves the metropolitan region of London is composed of two primary airports; London/Heathrow (LHR-EGLL) and London/Gatwick (LGW-EGKK) and three secondary airports; London/Stansted (STN-EGSS), London/Luton (LTN-EGGW) and London/City (LCY-EGLC). This multi-airport system is, with New York and Los Angeles, one of the most mature and complex multi-airport system in the world.





a. London/Heathrow (LHR): Original airport (primary)

London/Heathrow is located 14 miles west of the center of city of London. It was built in 1930. After being used as a military facility during WWII, the airport reopened to civil use in 1946. The airport remained the major primary airport serving the region since that period.

Congestion of primary airports: London/Heathrow is one of the most congested airports in the world. According to the 2003, ACI/IATA/ATAG Airport Capacity Demand / Demand Profiles report[1], the runway of London/Heathrow was "near saturated most of the day" and the apron and terminal "near saturated at peak hours" in 2001.The capacity

[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland.

airport is limited to (i.e. declared at) 44 departures and 43 arrivals per hour and is limited by runway, ATC and apron considerations.

b. London/Gatwick (LGW): Original airport (primary)

London/Gatwick is located 25 miles south of the center of the city of London. It was built in the 1920s. In the 1920s and early 1930s it was used for general aviation and flying school activities. Commercial activities began in 1936. It was designated as second airport serving London metropolitan region and alternate airport to London/Heathrow in 1950. Major airport infrastructure improvements were performed at the end of the 1950s.

Congestion of primary airports: The last major capacity expansion of the airport was performed in 1979. At the time, an agreement was reach with the local council not to expand further before 2019. Recent proposals to build a second runway suitable for large jets at London/Gatwick led to protests about increased noise and pollution and demolition of houses and villages. The British government has now decided to expand London/Stansted and London/Heathrow instead of London/Gatwick[1]. According to the 2003, ACI/IATA/ATAG Airport Capacity Demand / Demand Profiles report[2], the runway of London/Gatwick was "near saturated most of the day" and the apron and terminal "near saturated at peak hours" in 2001.

c. London/Stansted (STN): Emerged secondary airport

London/Stansted is located 30 miles from the center of the London city. It was built in 1942 and used as a military base during World War II. It opened to civil use in 1969.

Entry of carriers (e.g. low-cost carriers): Beginning in 1966, London/Stansted was placed under BAA control and was used by holiday charter operators to avoid the higher costs associated with operating at London/Heathrow and London/Gatwick. Ryanair started offering service at London/Stansted in 1991 and contributed to the significant

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[1] Source: Airport Technology, Industry Projects page; *"Gatwick Airport Pier 6 Project, United Kingdom",* available at; http://www.airport-technology.com/projects/pier6/, last accessed; April 2008.
[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

growth of traffic observed at London/Stansted since the beginning of the 1990s. Low-cost carriers now account for over 80% of the total passenger traffic[1].

Changes of airport status; conversion from military to civil status: It was built in 1942 and use as a military base during World War II. It opened to civil use in 1969.

Upgrade of airport infrastructure: In 1984, airfield and terminal improvements were performed. The future expansion of the airport is constrained. *Stop Stansted Expansion* (SSE) is a campaign group opposed to the expansion of London/Stansted.

In 2007, a new £40m phase of development began (including terminal space).

"The Future of Air Transport" white paper of December 2003, gave support to a project of a second runway at London/Stansted. Well-organized anti-expansion organizations that used environmental impact statements as a blocking mechanism oppose the expansion project[2].

Congestion of primary airports: cf. London/Heathrow and London/Gatwick

Role of ownership and management of airports: London/Stansted is operated by BAA (Now Ferrovial).

[1] Source: Airport Technology, Industry Projects page; *"London Stansted Airport (STN/EGSS), United Kingdom",* available at; http://www.airport-technology.com/projects/stanstedairport/, last accessed; April 2008.

[2] Ibid.

d. London/Luton (LTN): Emerged secondary airport

London/Luton is located 27 miles from the center of the city of London. It opened in 1938[1] and was used as a Royal Air Force base during WWII[2].

Entry of carriers (e.g. low-cost carriers): The airport was used by charter airlines in the 1970s. Passenger traffic rose at the end of the 1980s due to the growing presence of Ryanair, however, Ryanair moved a large part of its operations to London/Stansted in 1991. EasyJet replaced Ryanair when it made London/Luton its hub.

Changes of airport status; conversion from military to civil status: London/Luton was returned to civil use in 1952.

Upgrade of airport infrastructure: Airport infrastructure (i.e. terminal) improvements were performed in 1999. In 2004, plans to expand the facilities to include a new runway were made public. However, local community groups opposed the project.

Congestion of primary airports: cf. London/Heathrow and London/Gatwick.

Role of ownership and management of airports: Since 1998, London/Luton remains publicly owned by Luton Borough Council and operated, managed and developed by a private consortium; London Luton Airport Operations Ltd, for a period of 30 years. In 2005 TBI plc (which owned London Luton Airport Operations Ltd) was taken over Airport Concessions & Development Ltd., (ACDL) a company owned by Abertis Infraestructuras (90%), and Aena Internacional (10%)[3].

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[1] Source: London Luton Airport website, Airport History page, available at; http://www.london-luton.co.uk/en/content/8/143/airport-history.html, last accessed; April 2008.

[2] Source: Airport Technology, Industry Projects page; *"London Luton Airport (LTN/EGGW), United Kingdom",* available at; http://www.airport-technology.com/projects/lutonairport/, last accessed; April 2008.

[3] Source: London Luton Airport website, Airport History page, available at; http://www.london-luton.co.uk/en/content/8/143/airport-history.html, last accessed; April 2008.

e. London/City (LCY): Secondary airport emerged through the construction of a new airport

London/City is located 7 miles from the center of London. It was built in 1986 and is a rare case of the construction of new airport closer to the city than existing airports at the time of the construction[1]. Due to its location, the airport is mostly used by business travelers.

Planning, Financing and Construction of new airport: In 1981, London Docklands Development Corporation undertakes study on the feasibility of a STOLport (short Take Off and Landing) city centre gateway in Docklands. After planning permission problems and a public inquiry, construction began on the site in 1986.

Transfer of traffic/Entry of carriers: Due to its small size, London/City did not replace any other airport in the metropolitan region (unlike the more common pattern of construction of a new airport and transfer of traffic).

Congestion of primary airports: cf. London/Heathrow and London/Gatwick
Limitations of existing airports: cf. London/Heathrow and London/Gatwick

Availability and acquisition of land area in the metropolitan region: The airport is built on London's Dockland[2].

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[1] Source: London City Airport website, Airport History, available at; http://www.londoncityairport.com/index.php?page=AirportHistory, last accessed; April 2008.
[2] Ibid.

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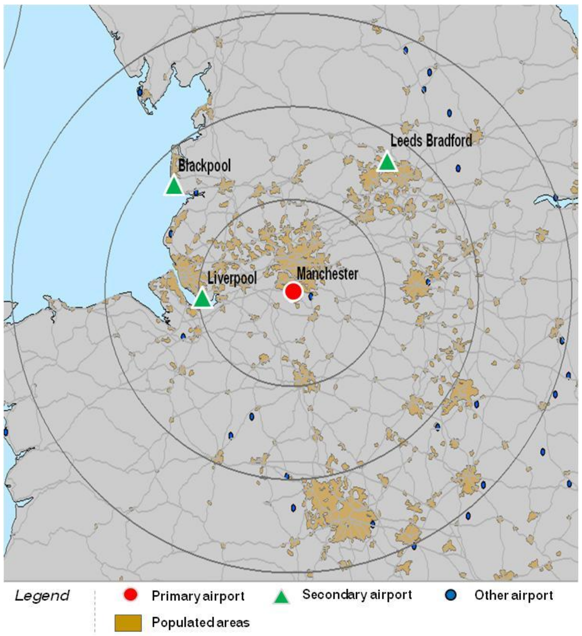
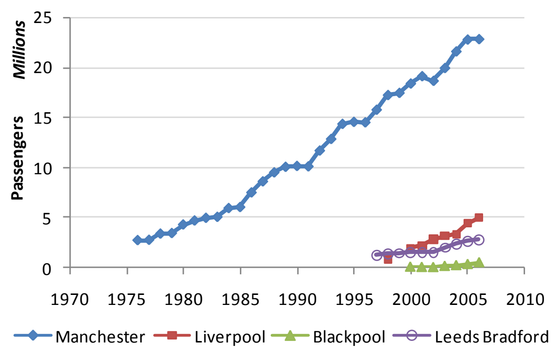
Appendix C-23: Europe - Manchester (United Kingdom)

The multi-airport system that serves the metropolitan region of Manchester is composed of one primary airport; Manchester/Intl (MAN-EGCC) and three secondary airports; Manchester/Liverpool (LPL-EGGP), Manchester/Leeds Bradford (LBA-EGNM) and Manchester/Blackpool (BLK-EGNH).





a. Manchester/Intl (MHT): Original airport (primary)

Manchester/Intl is located 9 miles from the center of the city of Manchester. It was built in 1930 and opened to commercial traffic in 1938. It has historically been (since 1938) the primary airport in the metropolitan region[1].

b. Manchester/Liverpool (LPL): Emerged secondary airport

Manchester/Liverpool is located 27 miles from the center of the city of Manchester. It was built in 1928 and opened in 1933[2].

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[1] Source: Airport Technology, Industry Projects page; *"Manchester Airport (MAN/EGCC), United Kingdom",* available at; http://www.airport-technology.com/projects/mancesterairport/, last accessed; April 2008.

[2] Source: Liverpool John Lennon Airport website, Background Information, History, available at: http://www.liverpoolairport.com/page.php?p=5, last accessed; April 2008.

Entry of carriers (e.g. low-cost carriers): Ryanair started offering scheduled service to Manchester/Liverpool in 1987, and established a base at Manchester/Liverpool in 2005[1].

Changes of airport status; conversion from military to civil status: Manchester/Liverpool was used by the Royal Air Force during WWII.

Upgrade of airport infrastructure: Following the acquisition of the airport by Peel Holdings Ltd., the airport was expanded (i.e. a new passenger terminal was constructed) in order to serve and accommodate growth from low-cost carriers[2].

Presence of secondary basins of population: Manchester/Liverpool (i.e. similarly to the three secondary airports that serve the Manchester region) is also serving the secondary basin of population of the city of Liverpool (i.e. population of the city 436,100 in 2005).

Congestion of primary airports: cf. Manchester/Intl

Role of ownership and management of airports: In 1990, the airport was privatized. It was acquired by Peel Holdings Ltd. in 2000.

c. Manchester/Leeds Bradford (LBA): Emerged secondary airport

Manchester/Leeds Bradford is located 35 miles from the center of Manchester. It was built in 1931 and opened to commercial traffic in 1935[3].

Entry of carriers (e.g. low-cost carriers): The growth of the airport after 2003 is mainly due to the entry and growth of Jet2.com (i.e. low-cost carrier).

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[1] Source: Ryanair website, available at: www.ryanair.com/, last accessed; March 2008.
[2] Source: Liverpool John Lennon Airport website, Background Information, History, available at: http://www.liverpoolairport.com/page.php?p=5, last accessed; April 2008.
[3] Source: Leeds Bradford International Airport website, History & Developments, available at: http://www.lbia.co.uk/airportcompany-aboutus-history.php, last accessed; April 2008.

Changes of airport status; conversion from military to civil status: The airport was used during WWII as a military base but civil operations returned shortly after the war in 1947.

Upgrade of airport infrastructure: The airport receiver infrastructure expansion (i.e. runway extensions) in the 1980s.

Presence of secondary basins of population: Leeds Bradford is located close to the cities of Leeds and Bradford that have population of 443,000 and 388,000 respectively (2001).

Role of ownership and management of airports: Manchester/Leeds Bradford was converted into a limited company under the provisions of the Airports Act 1986. In 2007, the airport was fully privatized (i.e. Bridgepoint). Plans to improve the passenger and the retail infrastructure were proposed.

d. Manchester/Blackpool (BLK): Emerged secondary airport

Manchester/Blackpool is located 38 miles from the center of the city of Manchester. It was built in 1909. It was used as a military airfield during WWII and scheduled traffic started in the 1949[1].

Entry of carriers (e.g. low-cost carriers): Several low-cost carriers started to offer schedule traffic at Manchester/Blackpool. Ryanair has been operating flights to London and Dublin from Blackpool since 2003[2]. Jet2.com established a base at Manchester/Blackpool in 2006.

Upgrade of airport infrastructure: In 1995, a new £2 million terminal building was declared open.

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[1] Source: Blackpool International Airport, History of Blackpool airport, available at; http://www.blackpoolinternational.com/about-us/history.php, last accessed; April 2008

[2] Ibid.

Presence of secondary basins of population: Manchester/Blackpool (i.e. similarly to the three secondary airports that serve the Manchester region) is also serving the secondary basin of population of the city of Blackpool (i.e. population of the city 142,700).

Congestion of primary airports: cf. Manchester/Intl

Role of ownership and management of airports: Blackpool Corporation assumed control of the airport from the Ministry of Aviation in April 1962. In 1987, Manchester/Blackpool was turned into a Private Limited Company with the Council holding 100% of the shares[1]. As of 2008, the airport was owned by MAR Properties.

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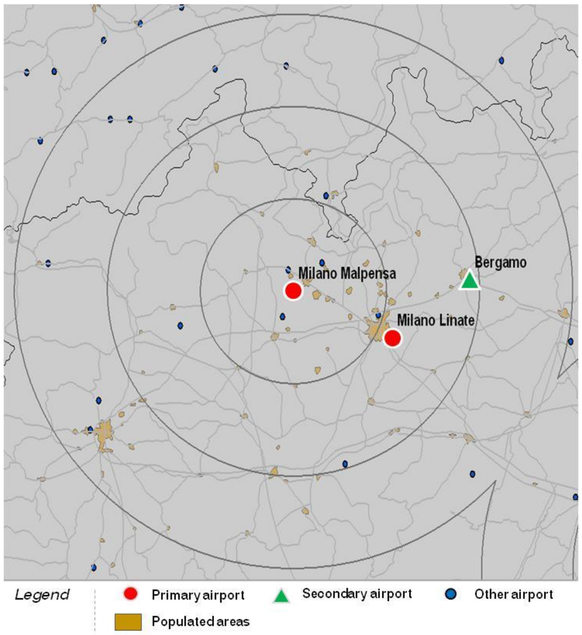
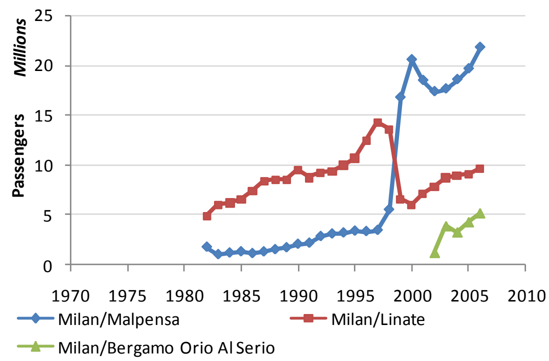
[1] Source: Blackpool International Airport, *"History of Blackpool airport",* available at; http://www.blackpoolinternational.com/about-us/history.php, last accessed; April 2008

Appendix C-24: Europe - Milan (Italy)

The multi-airport system that serves the region of Milan is composed of two primary airports; Milan/Malpensa (MXP-LIMC) and Milan/Linate (LIN-LIML) and one secondary airport; Milan/Bergamo Orio Al Serio (BGY-LIME).





a. Milan/Linate (LIN): Original airport (primary)

Milan/Linate is located 5 miles from the center of Milan. It was built in the 1930s and was the original airport serving Milan. International traffic was transferred to Milan/Malpensa. The airport is now used mostly for domestic and short-haul international flights.

b. Milan/Malpensa (MXP): Original airport (primary)

Milan/Malpensa is located 24 miles from the center of Milan. Before major improvement work carried out in 1998, the airport was used mostly for long-haul flights to the United States, South Africa, and Asia. Flights to Europe, Middle East and North Africa used Milan/Linate.

Congestion of primary airports: Because of flight delays and inconvenience, Milan/Malpensa was assessed as one of the worst major airports in Europe by the EU oversight committee governing airports.

c. Milan/Bergamo Orio Al Serio (BGY): Emerged secondary airport

Milan/Bergamo Orio Al Serio is located 27 miles from the center of the Milan region. It was constructed in 1937 as a military base and opened for civilian traffic in 1972. The airport now serves 33 airlines mainly low cost carriers.

Entry of carriers (e.g. low-cost carriers): Ryanair started to offer schedule traffic at Milan/Bergamo Orio Al Serio in 2004. Wizzair and MyAir (i.e. low-cost carriers) followed the entry of Ryanair.

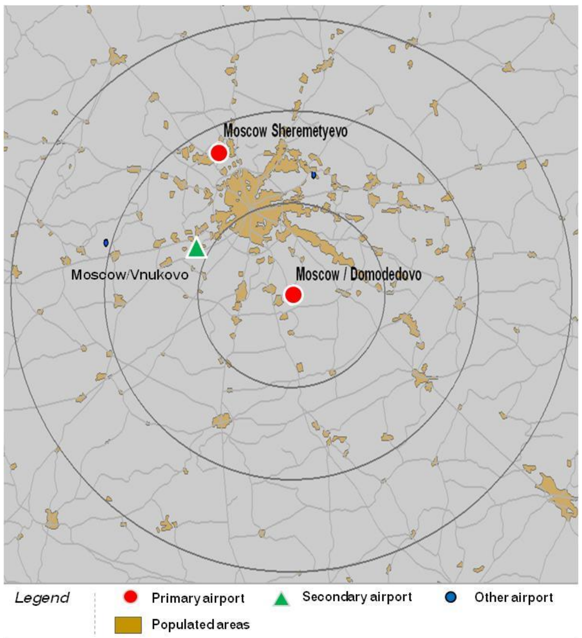
Changes of airport status; conversion from military to civil status: The airport was constructed in 1937 as a military base and opened for civilian traffic in 1972.

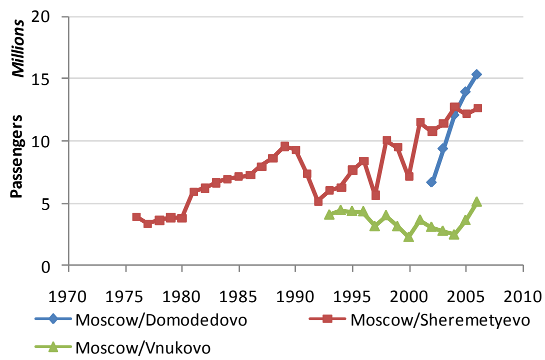
Presence of secondary basins of population: Milan/Bergamo Orio Al Serio is located 3 miles from the city of Bergamo in Lombardy, northeast of Milan. The city of Bergamo had a population of 117,000. This city is also located within the Province of Bergamo which had population of 1,022,000 in 2006.

Congestion of primary airports: cf. Milan/Malpensa and Milan/Linate

Appendix C-25: Europe - Moscow (Russia)

The multi-airport system that serves the metropolitan region of Moscow is composed of two primary airports; Moscow/Domodedovo (DME-UUDD), Moscow/Sheremetyevo (SVO-UUEE) and one secondary airport; Moscow/Vnukovo (VKO-UUWW) (i.e. original airport).





a. Moscow/Vnukovo (VKO): Original airport (secondary)

Moscow/Vnukovo is located 18 miles from the center of the city of Moscow. It was built in 1937 and opened in 1941. It was used as a military base during World War II. Commercial traffic was started after the war. The airport was the primary airport in the region until the construction of Moscow/Sheremetyevo in 1960[1].

Congestion of primary airports: According to the 2003, ACI/ATAG/IATA Airport Capacity Demand / Demand Profiles report[2], the runway, apron and terminal systems at Moscow/Vnukovo were "near saturated at peak hours" in 2001. Capacity of the airport is limited by runway, apron, ATC, terminal and noise considerations.

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[1] Source: Airport Technology, Industry Projects page; *"Vnukovo International Airport Expansion Project, Moscow, Russia"*, available at; http://www.airport-technology.com/projects/vnukovoexpansion/, last accessed; April 2008.
[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

b. Moscow/Sheremetyevo (SVO): Primary airport emerged through the construction of a new airport & upgrade

Moscow/Sheremetyevo is located 17 miles from the center of the city of Moscow. It was opened in 1959[1]. Ambitious plans to upgrade the airport were established. These plans include a new terminal that would triple the capacity of the airport[2].

c. Moscow/Domodedovo (DME): Primary airport emerged through the construction of a new airport

Moscow/Domodedovo is located 25 miles from the center of the city of Moscow. It was opened in 1964. Due to poor service at Moscow/Sheremetyevo, major international airlines transferred their operations at Moscow/Domodedovo in 1996[3]. In response to significant increase in passenger numbers, the airport is currently undergoing a major expansion program, which is scheduled to continue until 2020, with an anticipated total cost of $600 million[4].

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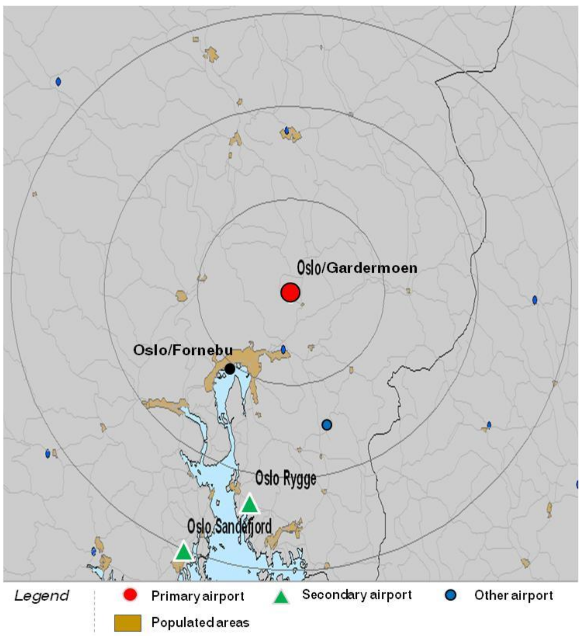
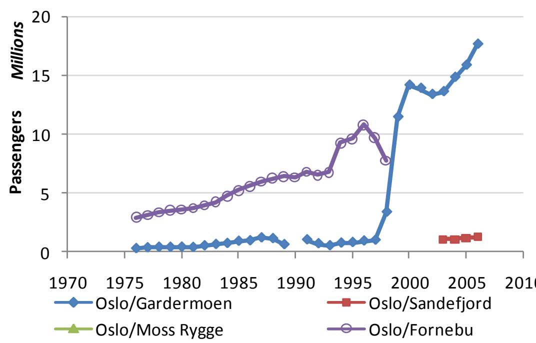
[1] Source: Airport Technology, Industry Projects page; *"Sheremetyevo International Airport (SVO/UUEE), Moscow, Russia",* available at; http://www.airport-technology.com/projects/moscow/, last accessed; April 2008.
[2] Ibid.
[3] Source: Airport Technology, Industry Projects page; *"Domodedovo International Airport (DME/UUDD), Moscow, Russia",* available at; http://www.airport-technology.com/projects/domodedovo/, last accessed; April 2008.
[4] Ibid.

Appendix C-26: Europe - Oslo (Norway)

The multi-airport system that serves region of Oslo is composed of one primary airport; Oslo/Gardermoen (OSL-ENGM) and one secondary airport; Oslo/Sandefjord (TRF-ENTO). The region had another primary airport that was closed after the construction of Oslo/Gardermoen and also features one potential secondary; Oslo/Moss Rygge (RYG-ENRY).





a. Oslo/Fornebu: Closed airport

Oslo/Fornebu was located 4 miles from the center of the city of Oslo. It was built in 1939 and served as a primary airport until its closure in 1998[1].

Congestion of primary airports and limitations of existing airports: Oslo/Fornebu was initially dimensioned for 2 million passengers per year. By 1996, the annual number of passengers had reached 10 million. Oslo/Fornebu had only one operational runway and strong expansion limitations due to the presence of the sea surrounding the airport footprint.

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[1] Source: Airport Technology, Industry Projects page; *"Gardermoen Airport (GEN/ENGM), Oslo, Norway",* available at; http://www.airport-technology.com/projects/gardermoen_as/, last accessed; April 2008.

b. Oslo/Gardermoen (OSL): Emerged primary airport

Oslo/Gardermoen is located 21 miles from the center of the city of Oslo. It was built in 1912 as a military airfield. After WWII, Oslo/Gardermoen was used for charter and military. Until 1998, the airport remained almost not utilized for scheduled commercial services.

Changes of airport status; conversion from military to civil status: The airport was initially a military base.

Upgrade of airport infrastructure & re-construction of the airport: In 1992, the Norwegian government made a final decision to upgrade the current militia and civil airfield into Oslo/Gardermoen.

Transfer of traffic/Entry of carriers: In 1998, all flights were transferred from Oslo/Fornebu to Oslo/Gardermoen[1].

Congestion of primary airports: cf. Oslo/Fornebu

c. Oslo/Sandefjord (TRF): Emerged secondary airport

Oslo/Sandefjord, also known as Oslo/Torp, is located 54 miles from the center of the city of Oslo. It was built in the 1940s and was used as a military base after WWII.

Entry of carriers (e.g. low-cost carriers): In 1998 Ryanair started offering scheduled service at Oslo/Sandefjord. Other low-cost carriers followed Ryanair's entry (i.e. Wizzair)[2].

---

[1] Source: Airport Technology, Industry Projects page; *"Gardermoen Airport (GEN/ENGM), Oslo, Norway",* available at; http://www.airport-technology.com/projects/gardermoen_as/, last accessed; April 2008.

[2] Source: Oslo/Sandefjord airport website; available at: http://www.torp.no/, last accessed; April 2008.

Changes of airport status; conversion from military to civil status: The airport was a NATO air base after WWII and returned to civil use.

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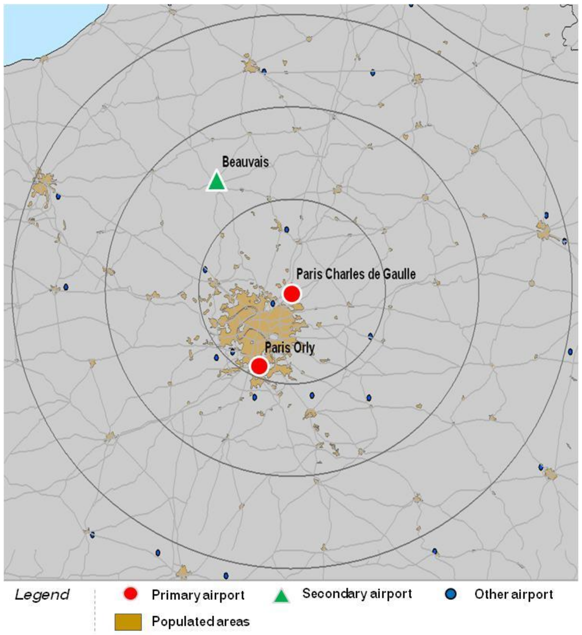
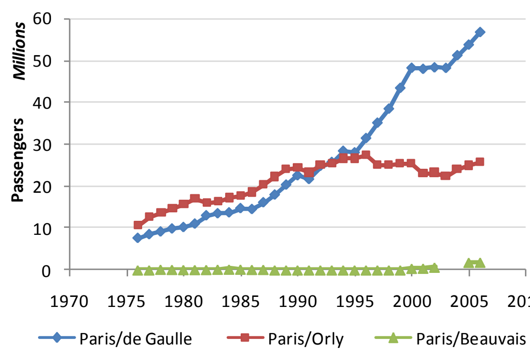
Appendix C-27: Europe - Paris (France)

The multi-airport system that serves the metropolitan region of Paris is composed of two primary airports; Paris/Orly (ORY-LFPO) and Paris/de Gaulle (CDG-LFPG) and one secondary airport; Paris/Beauvais (BVA-LFOB).





a. *Paris/Orly (ORY): Original airport (primary)*

Paris/Orly is located 8 miles from the center of the city of Paris. It was built in 1932 as a second airport (at the time Paris/Le Bourget was the primary airport, closed in 1977 to scheduled traffic and remains a business aviation airport). It was used as a military airport during WW II and return to civil use in 1948. It remained the main airport in the region[1].

Congestion of primary airports and limitations of existing airports: Paris/Orly is constrained but urban development limiting the ability to expand the airport footprint.

[1] Source: History of Aéroports de Paris website, "*History of Aéroports de Paris from 1945 to 1981*", available at; http://www.aeroportsdeparis.fr/Adp/en-GB/Groupe/Presentation/Histoire/De1945A981/, last accessed; April 2008

b. Paris/de Gaulle (CDG): Primary airport emerged through the construction of a new airport

Paris/de Gaulle is located 15 miles north east of the center of Paris.

Identification of a need to build a new airport: In the 1960s, the growth of traffic in the metropolitan region coupled with the expansion constraints of Paris/Orly motivated the need for a new airport in the region[1].

Planning, Financing and Construction of new airport: The construction of Paris/de Gaulle began in 1966 and the airport opened in 1974.

Transfer of traffic/Entry of carriers: After the opening of Paris/de Gaulle, international traffic was transferred from Paris/Orly.

Congestion of primary airports: cf. Paris/Orly
Limitations of existing airports: cf. Paris/Orly

c. Paris/Beauvais (BVA): Emerged secondary airport

Paris/Beauvais is located 42 miles from the center of the city of Paris. It was built in the 1930s and opened to commercial use in 1956.

Entry of carriers (e.g. low-cost carriers): Paris/Beauvais emerged as a secondary airport in the Paris region at the end of the 1990s and 2000s with the entry of Ryanair in 1997[2]. As of 2007, the airport now serves by 5 low-cost carriers (i.e. Ryanair, Wizzair, Blue Air, Centralwings, blueislands).

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[1] Source: History of Aéroports de Paris website, "*History of Aéroports de Paris from 1982 to 2006*", available at; 2008http://www.aeroportsdeparis.fr/Adp/en-GB/Groupe/Presentation/Histoire/De1982ANosJours/, last accessed; April 2008
[2] Source: Paris/Beauvais website, available at: http://www.aeroportbeauvais.com/, last accessed; April 2008.

Changes of airport status; conversion from military to civil status: Paris/Beauvais was used as a military base during WWII and opened to civil use in 1956.

Upgrade of airport infrastructure: The airport infrastructure was upgraded during WWII.

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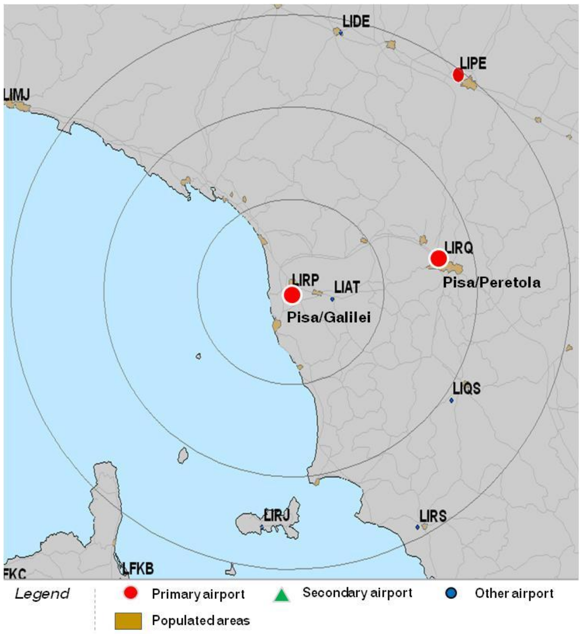
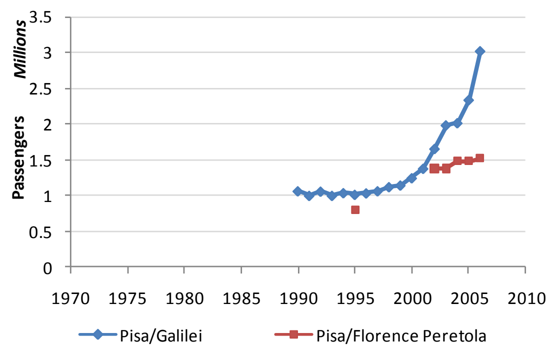
Appendix C-28: Europe - Pisa (Italy)

The multi-airport system that serves the region of Pisa is composed of two primary airports; Pisa/Galilei (PSA-LIRP) and Pisa/Florence Peretola (FLR-LIRQ).





a. *Pisa/Galilei (PSA): Original airport (primary)*

Pisa/Galilei is located 3 miles from the center of the city of Pisa. It was built in 1909 and has traditionally been the primary airport serving the region[1]. The airport is also jointly used by the military as an Italian air force base.

Entry of carriers (e.g. low-cost carriers): Pisa/Galilei was able to attract low-cost carrier airlines. Ryanair started to offer service at Pisa/Galilei in 1998 and a base in 2005[2]. Other low-cost carriers are serving Pisa/Galilei (i.e. easyJet, Jet2.com).

Role of ownership and management of airports: Pisa/Galilei is owned and managed by Società Aeroporto Toscano (SAT)[3].

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[1] Source: Galileo Galilei International Airport website, *"The Dawning of Civil Aviation"*, available at: http://www.pisa-airport.com/sat/cda/aree/index.php?idArea=12&idSection=32, last accessed; April 2008.
[2] Source: Ryanair website, *"History of Ryanair"*, available at: http://www.ryanair.com/site/EN/about.php, last accessed; April 2008.
[3] Source: Galileo Galilei International Airport website, *"The Dawning of Civil Aviation"*, available at: http://www.pisa-airport.com/sat/cda/aree/index.php?idArea=12&idSection=32, last accessed; April 2008.

b. Pisa/Florence Peretola (FLR): Original airport (primary)

Pisa/Florence Peretola is located 41 miles from the center of the city of Pisa. It was built in 1930s.

According to Società Aeroporto Toscano (SAT), Pisa/Florence Peretola and Pisa/Galilei are marketed as serving; *"the valley [Arno Valley that connects the cities of Pisa and Florence] that looks like a single metropolis with two airports at either end. All major world metropolises are served by two or more airports. Tuscany is no exception, with two airports located only 80 kilometers apart: Pisa Airport, by the coast, with a vocation as Tuscany's regional airport, and Florence Airport, serving mainly as the regional capital's city airport*"[1].

Presence of secondary basins of population: Pisa/Florence Peretola serves the city of Florence (population; 366,000 in 2006).

Upgrade of airport infrastructure: Since 1999, initiatives for restructuring and expansion of Pisa/Florence Peretola were undertaken. These involved new terminals, aircraft parking areas and other areas dedicated to the operational and commercial management of the airport[2].

Role of ownership and management of airports: Pisa/Galilei is owned and managed by Aeroporto de Firenze (AdF).

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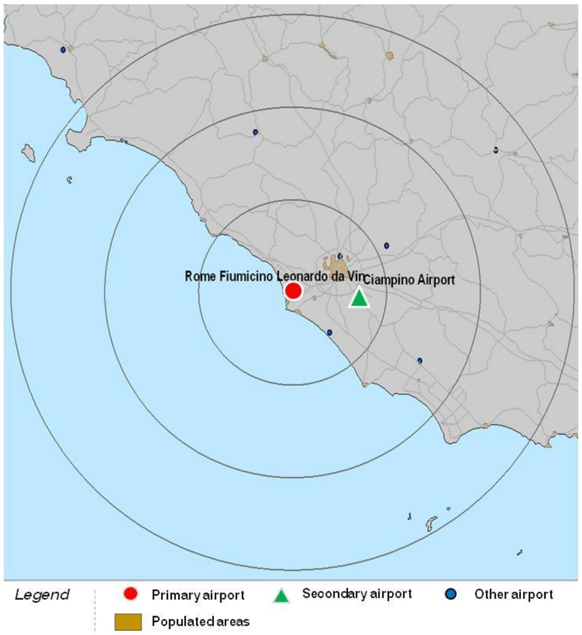
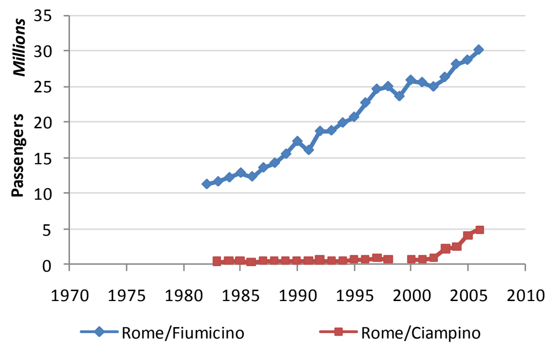
[1] Source: Galileo Galilei International Airport website, *"The Arno Valley"*, available at: http://www.pisa-airport.com/sat/cda/aree/index.php?idArea=21, last accessed; April 2008

[2] Source: Aeroporto de Firenze website, Florence Peretola Airport, *"Adf - Company - Presentation"*, available at: http://www.aeroporto.firenze.it/EN/index.php?percorso=contents&jk=55&curr=48, last accessed; April 2008

Appendix C-29: Europe - Rome (Italy)

The multi-airport system serving the region of Rome is composed of one primary airport; Rome/Fiumicino (FCO-LIRF) and one secondary airport; Rome/Ciampino (CIA-LIRA).





a. Rome/Ciampino (CIA): Original airport (secondary)

Rome/Ciampino is located 8 miles south-east of the city of Rome. Even though the airport was a secondary airport (i.e. relative to the set of airports serving the region) in 2006, it was originally the primary airport in the region. Rome/Ciampino was built in 1916.

Congestion of primary airports and limitations of existing airports: Rome/Ciampino has one single runway and its expansion was constrained. Even after its reemergence phase, the expansion of Rome/Ciampino is still limited. Local community pressure attempted to curb traffic in 2007.

<u>*Re-emergence phase:*</u>

Since the early 2000s, Rome/Ciampino experienced a significant increase in traffic due the entry of low-cost carriers.

Entry of carriers (e.g. low-cost carriers): The airport is now served mostly by low-cost carriers; Ryanair (2004)[1], Centralwings, EasyJet, and WizzAir.

Upgrade of airport infrastructure: In order to accommodate growth from low-cost carriers, airport infrastructure development plans are under study.

Presence of secondary basins of population: Rome/Ciampino is located closer to the city of Rome than Rome/Fiumicino. As a result it remains an attractive airport from an access standpoint.

b. Rome/Fiumicino (FCO): Primary airport emerged through the construction of a new airport

Rome/Fiumicino is located 14 miles west of the city of Rome. It was opened in 1961 and followed with the transfer of traffic from Rome/Ciampino.

Identification of a need to build a new airport: cf. Rome/Ciampino (initial phase)

Planning, Financing and Construction of new airport: Rome/Ciampino opened in 1961.

Transfer of traffic/Entry of carriers: Passenger traffic was transferred Rome/Ciampino. Rome/Ciampino remained utilized for domestic and charter flights.

Congestion of primary airports and limitations of existing airports: cf. Rome/Ciampino (initial phase).

[1] Source: Ryanair website, *"History of Ryanair",* available at: http://www.ryanair.com/site/EN/about.php, last accessed; April 2008.

a. Rome/Viterbo: Potential secondary airport

Rome/Viterbo is located north of Rome. It has officially been designated as Rome's third airport by Italy's ministry of transport. Rome/Viterbo is currently used as a military base and by private aviation.

Congestion of primary airports and limitations of existing airports: A third airport for Rome has become urgent since protests at Rome/Ciampino over noise and air pollution have led to cutbacks in air traffic, although low-cost airline Ryanair, which has the virtual monopoly of slots at Rome/Ciampino, is still contesting reductions[1].

Availability of airport infrastructure in the metropolitan region: Frosinone and Latina airport were also considered as potential secondary airports[2].

[1] Source: Forbes.com, *"Italy chooses Viterbo as Rome's third airport",* available at: http://www.forbes.com/markets/feeds/afx/2007/11/27/afx4376248.html, last accessed; April 2008.
[2] Ibid.

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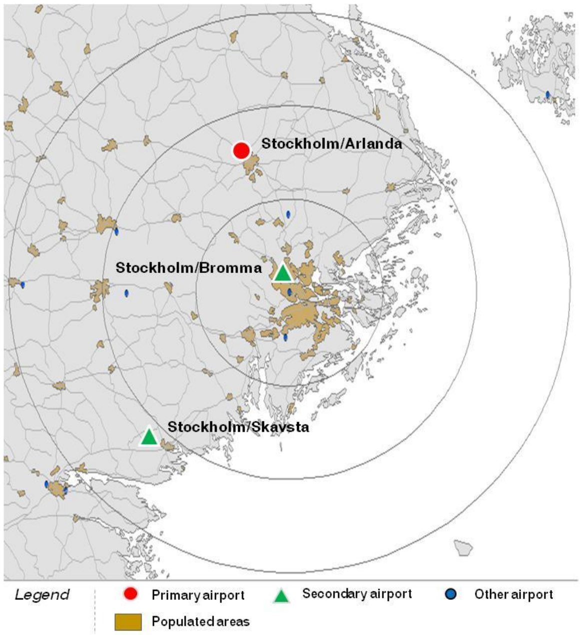
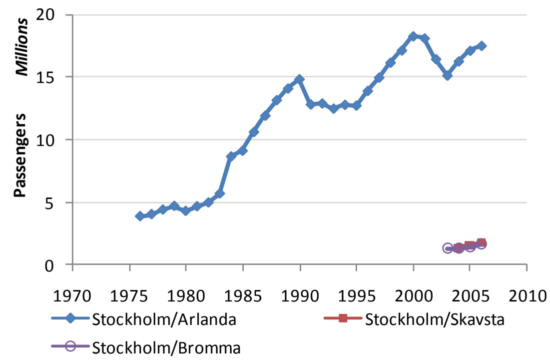
Appendix C-30: Europe - Stockholm (Sweden)

The multi-airport system that serves the metropolitan region of Stockholm is composed of one primary airport; Stockholm/Arlanda (ARN-ESSA), and two secondary airports; Stockholm/Bromma (BMA-ESSB) and Stockholm/Skavsta (NYO-ESKN).





a. Stockholm/Bromma (BMA): Original airport (secondary)

Stockholm/Bromma is located 5 miles from the center of Stockholm city[1]. It was opened in 1936. It was the primary airport in the metropolitan region until the construction of Stockholm/Arlanda. Traffic was transferred in 1960 (i.e. international flights) and 1983 (i.e. domestic flights) to Stockholm/Arlanda. The airport has not been closed and remains competitive due to strategic location (i.e. proximity to center of Stockholm). There is however pressure from local communities to close it.

Congestion of primary airports and limitations of existing airports: Stockholm/Bromma was heavily congested in the 1950s and had limited expansion capabilities (i.e. surrounded by dense urban development).

[1] Source: Stockholm Bromma Airport website, available at; http://www.lfv.se/, last accessed; April 2008.

b. Stockholm/Arlanda (ARN): Primary airport emerged through the construction of a new airport

Stockholm/Arlanda is located 25 miles north of the center of Stockholm city. It was built in 1959 and opened in 1960[1].

Identification of a need to build a new airport: Stockholm/Bromma was heavily congested in the 1950s and had limited expansion capabilities (i.e. surrounded by dense urban development).

Planning, Financing and Construction of new airport: The airport was built in 1959 and opened in 1960.

Transfer of traffic/Entry of carriers: In 1983, domestic flights were transferred from Stockholm/Bromma.

Congestion of primary airports: cf. Stockholm/Bromma
Limitations of existing airports: cf. Stockholm/Bromma

[1] Source: Stockholm Arlanda Airport website, available at; http://www.arlanda.se/en/About-the-airport/, last accessed; April 2008.

c. *Stockholm/Skavsta (NYO): Emerged secondary airport*

Stockholm/Skavsta is located 55 miles from the center of the city of Stockholm. It was built in the 1940s and was used as military air base. The airport became civil airport in 1984.

Entry of carriers (e.g. low-cost carriers): Stockholm/Skavsta was able to attract low-cost carrier airlines. Ryanair started to offer service at Stockholm/Skavsta in 1997 and a base in 2003. In 2003, Wizzair also started offering scheduled service at Stockholm/Skavsta[1].

Changes of airport status; conversion from military to civil status: Stockholm/Skavsta was established as a military air base in the 1940s but was closed 1980. It was developed into a civilian airport in 1984[2].

Upgrade of airport infrastructure: A new terminal with a capacity of 2.5 million passengers a year was constructed[3].

Presence of secondary basins of population: 27% of Sweden's population (2.4 million), lives within Stockholm Skavsta's catchment area (a 100 km radius).

Role of ownership and management of airports: Stockholm/Skavsta is owned and managed by TBI incorporated in the United Kingdom (which was acquired by Airport Concessions and Development Limited (ACDL), owned by Spanish companies Abertis Infraestructuras S.A. in 2004, that later was acquired by Abertis. The Nyköping Municipality still has a 9.9 % owner share.

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[1] Source: Stockholm Skavsta Airport website; available at; http://www.skavsta.se/en/content.asp?area=4&id=196, last accessed; April 2008

[2] Ibid.

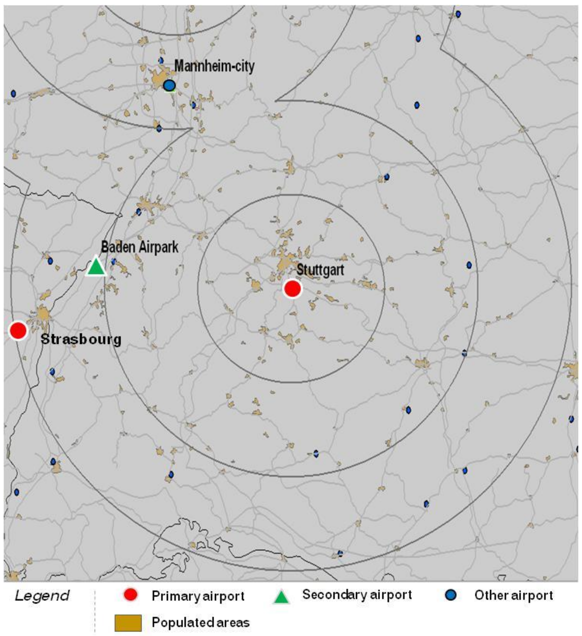
[3] Ibid.

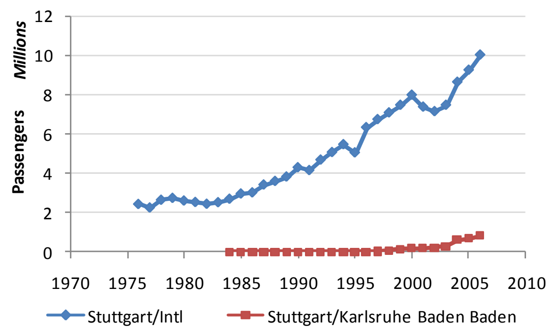
d. Stockholm/Vasteras (VST): Potential secondary airport

Stockholm/Vasteras is located 55 miles from the center of the city of Stockholm. It was built in 1944 and was used as military base. The base closed in 1983. From 1983 to 1999, the airport was leased by the local municipality and sold in 1999.

Appendix C-31: Europe - Stuttgart (Germany)

The multi-airport system serving the region of Stuttgart is composed of one primary airport; Stuttgart/Intl (STU-EDDS) and one secondary airport; Stuttgart/Karlsruhe Baden Baden (FKB-EDSB)[1].





a. Stuttgart/Intl (STU): Original airport (primary)

Stuttgart/Intl is located 6 miles from the center of the city of Stuttgart. It was built in 1936 and opened in 1939 and it has been the primary airport serving the region since that time.

b. Stuttgart/Karlsruhe Baden Baden (FKB): Emerged secondary airport

Stuttgart/Karlsruhe Baden Baden is located 50 miles from the center of Stuttgart. It was constructed in the 1950s as a Canadian military base (i.e. CFB Baden-Soellingen).

Entry of carriers (e.g. low-cost carriers): In September 2003, Ryanair starts offering scheduled service from Stuttgart/Karlsruhe Baden Baden to London/Stansted[1]. Other

[1] Note: Stuttgart/Karlsruhe Baden Baden is located 21 miles from the center of the city of Strasbourg in France and 28 miles from the Strasbourg airport. Baden could also be considered as part of an extended multi-airport system between Stuttgart and Strasbourg since it also serves the Strasbourg region (despite the fact that the Stuttgart/Karlsruhe Baden Baden and the city of Strasbourg are located in different countries). Ryanair also offers ground connections between the city of Strasbourg and Stuttgart/Karlsruhe Baden Baden.

airlines followed the entry of Ryanair (i.e. Air Berlin, Air Via, Freebird Airlines, Hamburg International, Sky Airlines, SunExpress and TUIfly)[2].

Changes of airport status; conversion from military to civil status: From 1953 to 1993, the airport was a Canadian military air base. It was transferred to civil use in 1993 and opened in 1997.

Role of ownership and management of airports: Stuttgart/Karlsruhe Baden Baden is owned and operated by a private group of investors.

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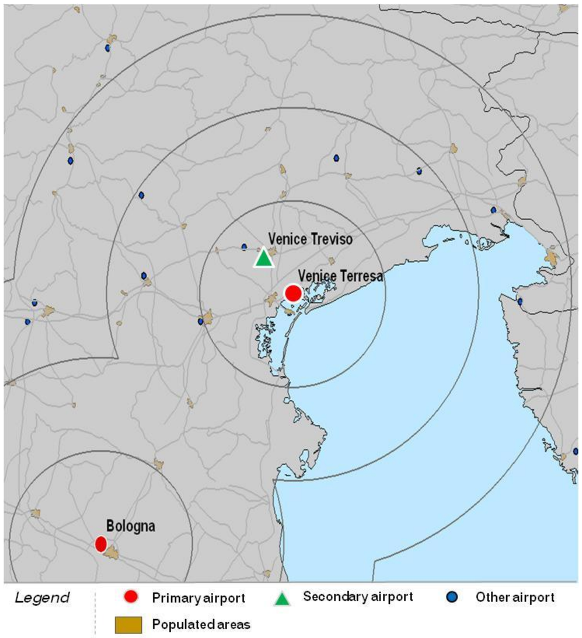
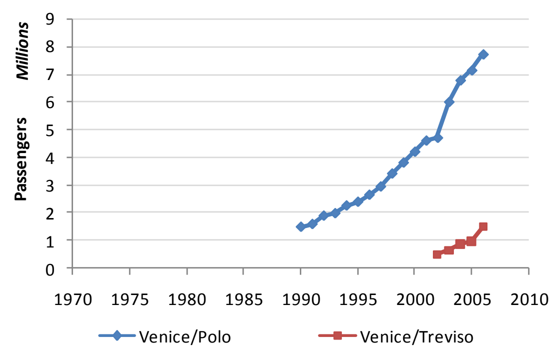
[1] Source: Stuttgart/Karlsruhe Baden Baden website, Airport history, available at; http://www.badenairpark.de/, last accessed; March 2008.

[2] Source: Stuttgart/Karlsruhe Baden Baden website, Airport history, available at; http://www.badenairpark.de/, last accessed; March 2008.

Appendix C-32: Europe - Venice (Italy)

The multi-airport that serves the metropolitan region of Venice is composed of one primary airport; Venice/Polo (VCE-LIPZ) and one secondary airport; Venice/Treviso (TSF-LIPH).





a. Venice/Polo (VCE): Original airport (primary)

Venice/Polo[1] is located 5 miles from the center of the city of Venice. It has historically been the main airport serving the region.

b. Venice/Treviso (TSF): Emerged secondary airport

Venice/Treviso is located 15 miles from the center of the city of Venice. It opened to commercial traffic in 1953.

Changes of airport status; conversion from military to civil status: The airport was originally a military air base (i.e. 2nd Squadron).

[1] Source: Venice Airport website; available at; http://www.veniceairport.com/, last accessed; April 2008

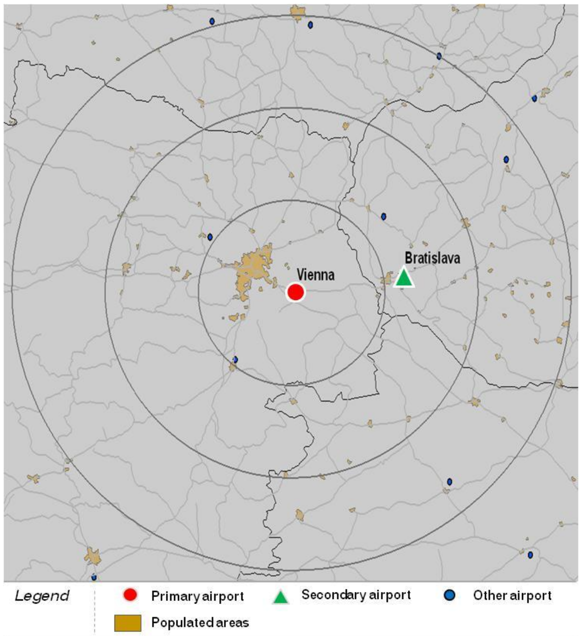
Entry of carriers (e.g. low-cost carriers): Venice/Treviso exhibited significant passenger traffic growth following the entry of Ryanair in 1998[1].

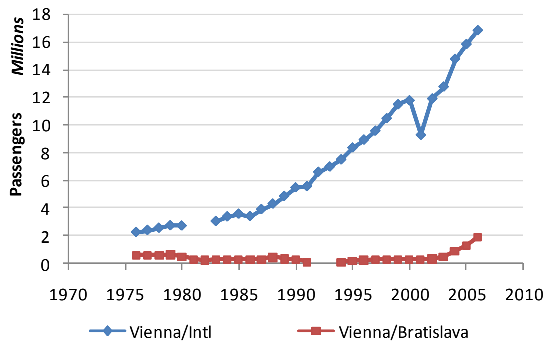
Role of ownership and management of airports: Venice/Treviso is owned by Aer Tre S.P.A. and managed by SAVE S.p.A[2].

[1] Source: Ryanair website, *"History of Ryanair",* available at: http://www.ryanair.com/site/EN/about.php, last accessed; April 2008.
[2] Source: Venice Airport website; available at; http://www.veniceairport.com/, last accessed; April 2008

Appendix C-33: Europe - Vienna (Austria)

The multi-airport system that serves the metropolitan region of Vienna is composed of one primary airport; Vienna/Intl (VIE-LOWW) and one secondary airport; Vienna/Bratislava (BTS-LZIB).





a. Vienna/Intl (VIE): Original airport (primary)

Vienna/Intl was built in 1938 as a military airfield. Vienna/Intl has been historically the primary airport in the region and this airport is reaching its capacity limit[1].

Congestion of primary airports: According to the 2003, Airport Capacity Demand / Demand Profiles report[2], the runway, apron and terminal of Vienna/Intl were "near saturated at peak hours" in 2001. The declared hourly peak hour capacity of the airport was 48 departures and 48 arrivals for a combined maximum of 66 hourly operations. The capacity of the airport was limited due to runway capacity (i.e. intersecting runways). In addition, Vienna/Intl was reaching capacity at the terminal level in the Non-Schengen area during departure peaks. A project aiming to increase the available terminal space and

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[1] Source: Airport Technology, Industry Projects page; *"Vienna Airport Skylink Project, Austria"*, available at; http://www.airport-technology.com/projects/viennaairport/, last accessed; April 2008.

[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

to bring the airport into a more efficient configuration to handle larger aircraft is under way. It also addresses the issue of separation between Schengen and non-Schengen operations[1].

Role of ownership and management of airports: Vienna/Intl is operated by Flughafen Wien AG, which is an independent Airport Authority owned by the local government with minority private shareholders (E).

b. Vienna/Bratislava (BTS): Emerged secondary airport

Vienna/Bratislava is located 29 miles east of Vienna/Intl, 39 miles from the center of Vienna and 5 miles from the city of Bratislava[2].

Entry of carriers (e.g. low-cost carriers): SkyEurope (i.e. low-cost airline) started to operate at Vienna/Bratislava in 2002. In 2007, SkyEurope reduced its flight offering at Vienna/Bratislava and transferred flights to Vienna/Intl.

Upgrade of airport infrastructure: The runways went through a complete reconstruction in the 1980s.

Presence of secondary basins of population: Vienna/Bratislava is located 5 miles from the city of Bratislava (population of 426,091), which the capital and largest city in Slovakia.

Congestion of primary airports: According to the 2003, Airport Capacity Demand / Demand Profiles report[3], the runway, apron and terminal of Vienna/Intl were "near saturated at peak hours" in 2001. The declared hourly peak hour capacity of the airport

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[1] Source: Airport Technology, Industry Projects page; *"Vienna Airport Skylink Project, Austria",* available at; http://www.airport-technology.com/projects/viennaairport/, last accessed; April 2008.
[2] Source: M.R.Štefánika Bratislava Airport, Airport history, available at: http://www.letiskobratislava.sk/32.html, last accessed; April 2008.
[3] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

was 48 departures and 48 arrivals for a combined maximum of 66 hourly operations. The capacity of the airport was limited due to runway capacity (i.e. intersecting runways).

Role of ownership and management of airports: Vienna/Bratislava was run by the state until 2004 and is now run by a public limited company (Airport Bratislava (BTS)). In 2006, a Vienna/Intl led consortium (Two One; Flughafen Wien AG and PENTA Investments Limited) attempted to take over the ownership and management of Vienna/Bratislava. However, the sale was cancelled on the basis of concerns about restriction of competition in the market and a situation resulting in a dominant position. This case of Vienna/Bratislava multi-airport system highlights some of the downsides of privatization on the control and ownership of airports within a region. Even though there may be a willingness, by a single owner/operator, to develop successfully multiple airports in a region (as it is the case with the Frankfurt multi-airport system), potential deviations from this goal may exist or be perceived by the various parties involved in the privatization process. In addition, the privatization process can become more complicated when it involves multiple countries.

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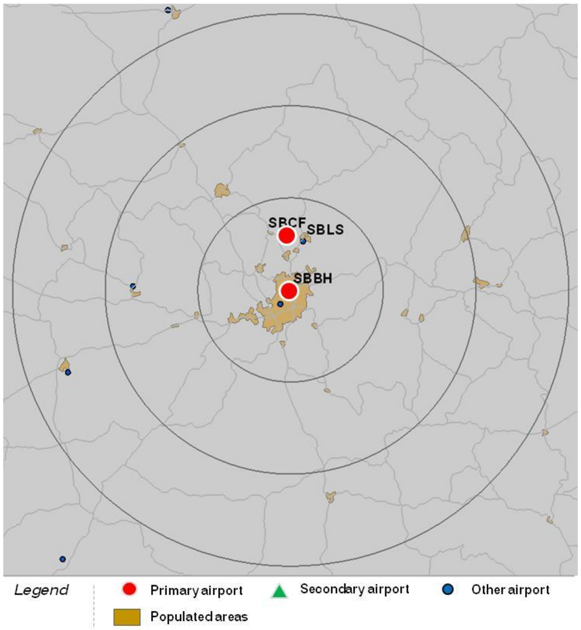
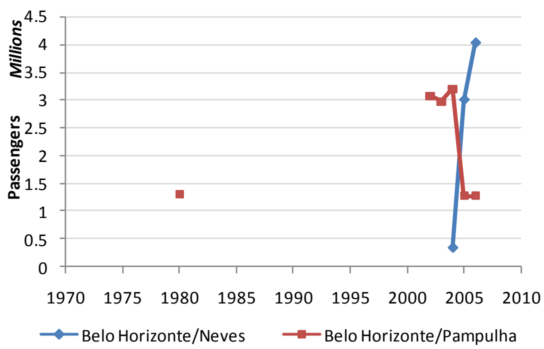
Appendix C-34: Latin America - Belo Horizonte (Brazil)

The multi-airport system that serves the Belo Horizonte metropolitan region is composed of two primary airports; Belo Horizonte/Pampulha (PLU-SBBH) and Belo Horizonte/Neves (CNF-SBCF).





a. Belo Horizonte/Pampulha (PLU): Original airport (primary)

Belo Horizonte/Pampulha is located 3 miles from the center of the city of Belo Horizonte. Belo Horizonte/Pampulha is now handling mostly domestic flights[1].

Congestion of primary airports and limitations of existing airports: The airport was congested in the 1970s-1980s which motivated the development of the primary airport in the region; Belo Horizonte/Neves. The expansion of the footprint of the airport is also heavily constrained by surrounding urban development.

[1] Source: Infraero Brazilian Airports website, "*Belo Horizonte Airport*", available at: http://www.infraero.gov.br/usa/aero_prev_home.php?ai=204, last accessed; April 2008.

b. Belo Horizonte/Neves (CNF): Primary airport emerged through the construction of a new airport

Belo Horizonte/Neves is located 17 miles from the center of the city of Belo Horizonte. The airport was built in 1980 and opened to commercial traffic in 1984.

Identification of a need to build a new airport: cf. Congestion and limitations of Belo Horizonte/Pampulha.

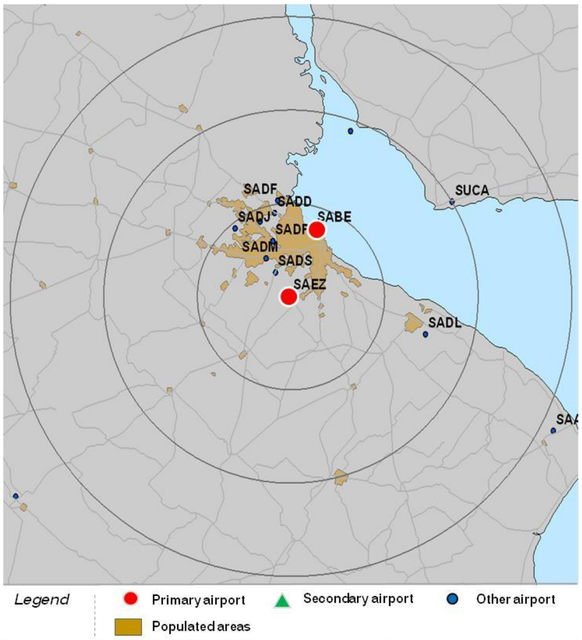
Planning, Financing and Construction of new airport: Despite the fact that the airport was built and opened in 1984, traffic remained at fairly low levels until 2005, due to the excessive distance from the center of the city and inadequate ground transportation.

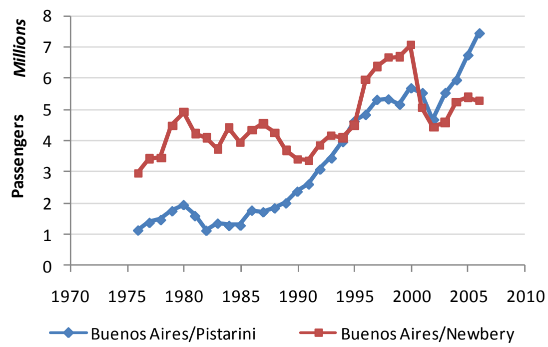
Transfer of traffic/Entry of carriers: In 2005, the Brazilian government transferred 130 daily flights from Belo Horizonte/Pampulha to Belo Horizonte/Neves. The result was an increasing annual passenger flow from 350,000 to approximately 3.0 million in 2005.

Congestion of primary airports: cf. Belo Horizonte/Pampulha
Limitations of existing airports: cf. Belo Horizonte/Pampulha

Appendix C-35: Latin America - Buenos Aires (Argentina)

The multi-airport system that serves the Buenos Aires metropolitan region is composed of two primary airports; Buenos Aires/Newbery (AEP-SABE) and Buenos Aires/Pistarini (EZE-SAEZ).





a. Buenos Aires/Newbery (AEP): Original airport (primary)

Buenos Aires/Newbery is located 2 miles from the center of the city of Buenos Aires. It was built in the 1940s and was historically the primary airport in the region.

Congestion of primary airports and limitations of existing airports: Buenos Aires/Newbery was constrained by urban development. As a result it was not possible to expand it.

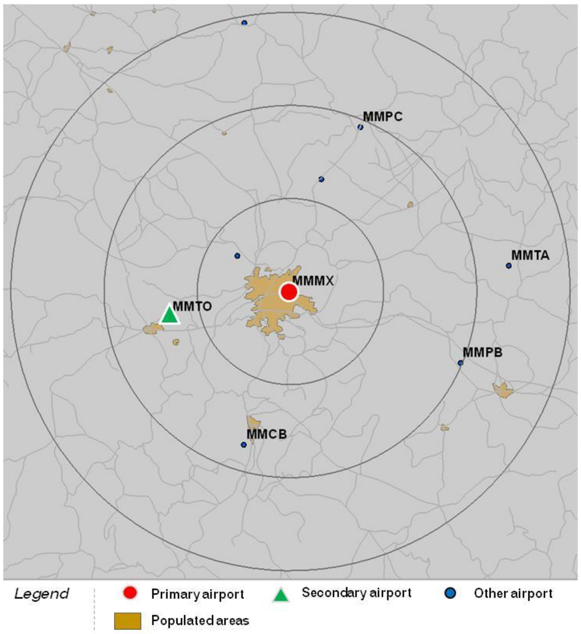
b. Buenos Aires/Pistarini (EZE): Primary airport emerged through the construction of a new airport

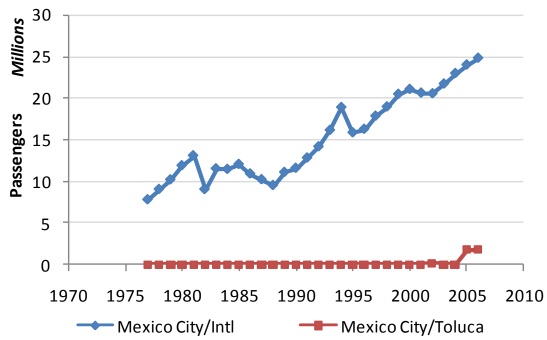
Buenos Aires/Pistarini is located 15 miles from the center of the city of Buenos Aires. It was built in 1944.

Role of regulatory and political factors: The airport had been privatized, as 32 other Argentinean airports (i.e. 30-year concession to an international consortium of businesses from Argentina, Italy and the United States; Aeropuertos Argentina 2000).

Appendix C-36: Latin America - Mexico (Mexico)

The multi-airport system that serves the metropolitan region of Mexico is composed of one primary airport; Mexico City/Intl (MEX-MMMX) and one secondary airport; Mexico City/Toluca (TLC-MMTO).





a. Mexico City/Intl (MEX): Original airport (primary)

Mexico City/Intl is located 4 miles from the center of the city of Mexico[1]. It was built in 1939 and has historically been the primary[2] airport in the region.

Congestion of primary airports: According to the 2003 Airport Capacity Demand / Demand Profiles report[3], the runway, terminal and apron of Mexico airport were "near saturated most of the day" in 2001. Runway considerations limit the capacity of the airport[4].

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[1] Source: Airport Technology, Industry Projects page; *"Benito Juárez International Airport (Aeropuerto Internacional De La Ciudad De México), Mexico"*, available at; http://www.airport-technology.com/projects/mexico/, last accessed; April 2008.

[2] Note: The planning process for a new airport in either Texcoco (State of Mexico) or Tizayuca (Hidalgo) underway in the 1990s and early 2000s. However, the plans have been abandoned due to opposition from local landowners.

[3] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[4] Ibid.

b. Mexico City/Toluca (TLC): Emerged secondary airport

Mexico City/Toluca is located 28 miles west of the center of the city of Mexico.

Entry of carriers (e.g. low-cost carriers): Mexico City/Toluca has emerged as a secondary airport following the entry and growth of low-cost carriers; Interjet (2005), Volaris (2006) [1,2], and Avolar.

Presence of secondary basins of population: Mexico City/Toluca is located 6 miles northwest of the city of Toluca, which is a rapidly growing urban area and now the fifth largest in Mexico. In 2005, the city of Toluca had 747,512 residents and its urban area had a population of 1,610,786 (UN2004).

Congestion of primary airports: cf. Mexico City/Intl

Role of ownership and management of airports: Mexico City/Toluca is part of the Mexico City Metropolitan Airport Group.

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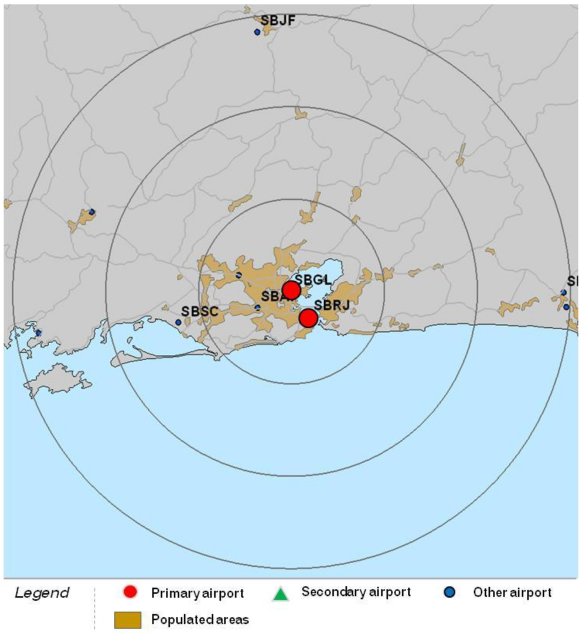
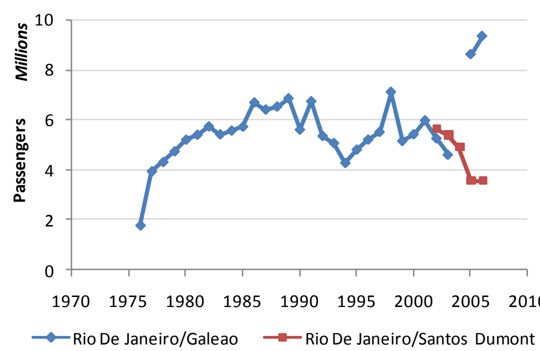
[1] Source: Volaris airlines, *"Airline history",* available at: http://www.volaris.com.mx/NuestraHistoria.aspx, last accessed; April 2008.
[2] Source: Volaris airlines, *"Route network",* available at: http://www.volaris.com.mx/DestinosUS.aspx, last accessed; April 2008.

Appendix C-37: Latin America - Rio de Janeiro (Brazil)

The multi-airport system that serves the metropolitan region of Rio de Janeiro is composed of two primary airports; Rio De Janeiro/Santos Dumont (SDU-SBRJ) and Rio De Janeiro/Galeao (GIG-SBGL).





a. Rio De Janeiro/Santos Dumont (SDU): Original airport (primary)

Rio de Janeiro/Santos Dumont airport is located 1 mile from the center of the city of Rio de Janeiro. It was built in the 1930s and has historically been the primary airport serving the metropolitan region. The airport handles mostly domestic flights[1].

Congestion of primary airports and limitations of existing airports: The airport was built on reclaimed land, leaving no space for expansion. The airport is heavily congested[2].

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[1] Source: Infraero Brazilian Airports website, "*Santos-Dumont Airport*", available at: http://www.infraero.gov.br/usa/aero_prev_home.php?ai=212, last accessed; April 2008.
[2] Ibid.

b. *Rio de Janeiro/Galeao (GIG): Primary airport emerged through the construction of a new airport*

Rio de Janeiro/Galeao is located 7 miles from the center of the city of Rio de Janeiro[1]. It was built in 1952 to alleviate the congestion at Rio de Janeiro/Santos Dumont and accommodate larger aircraft.

Identification of a need to build a new airport: cf. Rio de Janeiro/Santos Dumont

Planning, Financing and Construction of new airport: Rio de Janeiro/Galeao was built in 1952.

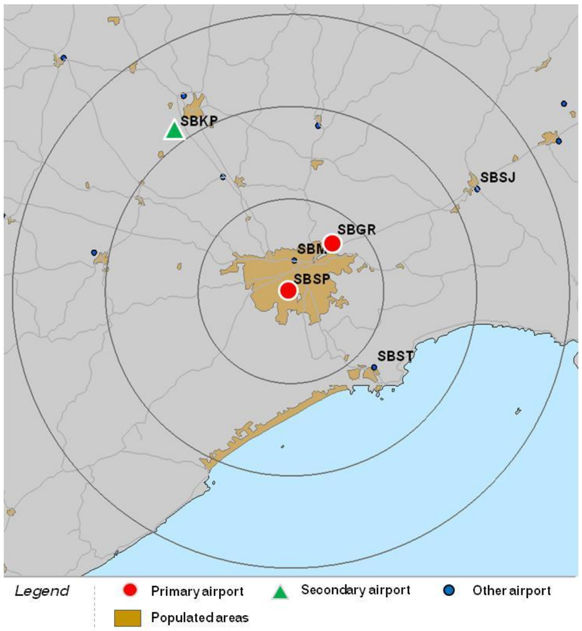
Transfer of traffic/Entry of carriers: In 2004, a significant number of flights were transferred from Rio De Janeiro/Santos Dumont to Rio de Janeiro/Galeao. This alleviated the capacity problem at Rio De Janeiro/Santos Dumont.

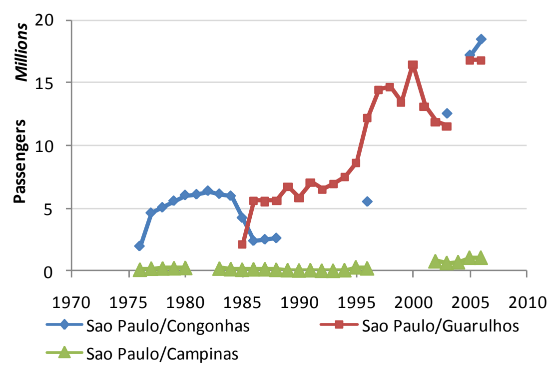
Congestion of primary airports and limitations of existing airports: cf. Rio de Janeiro/Santos Dumont**.**

[1] Source: Infraero Brazilian Airports website, "*Rio de Janeiro/Galeão - Antonio Carlos Jobim International Airport"*, available at: http://www.infraero.gov.br/usa/aero_prev_home.php?ai=213, last accessed; April 2008.

Appendix C-38: Latin America - Sao Paulo (Brazil)

The multi-airport system that serves the Sao Paulo metropolitan region is composed of two primary airports; Sao Paulo/Congonhas (CGH-SBSP) and Sao Paulo/Guarulhos (GRU-SBGR), and one secondary airport; Sao Paulo/Campinas (VCP-SBKP).





a. Sao Paulo/Congonhas (CGH): Original airport (primary)

Sao Paulo/Congonhas is located 4 miles from the center of the city of Sao Paulo. It opened in 1936. It serves mostly domestic traffic[1].

Congestion of primary airports and limitations of existing airports: Sao Paulo/Congonhas's expansion is limited due to its footprint and has short runways (i.e. longest runway 6,365 ft long). These runways constraints motivated the construction of Viracopos in the 1960s. Sao Paulo/Congonhas remained congested in the 1980s which motivated the construction of Sao Paulo/Guarulhos in 1985 and partial transfer of traffic[2].

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[1] Source: Congonhas/São Paulo International Airport website, available at; http://www.infraero.gov.br/usa/aero_prev_home.php?ai=219, last accessed; April 2008

[2] Ibid.

b. Sao Paulo/Campinas (VCP): Original airport (Construction of new airport and re-emergence as a secondary airport)

Sao Paulo/Campinas is located 51 miles from the center of Sao Paulo[1]. It was built in 1960 as a response to runway length limitations at Sao Paulo/Congonhas.

Identification of a need to build a new airport: cf. Sao Paulo/Congonhas (i.e. runway length limitations)

Planning, Financing and Construction of new airport: It was built and opened to passenger traffic in 1960.

Transfer of traffic/Entry of carriers: Partial transfer of flights was performed when Sao Paulo/Campinas opened in 1960. However, the excessive distance from the center of the city made the airport unattractive failed to capture traffic.

Congestion of primary airports: cf. Sao Paulo/Congonhas
Limitations of existing airports: cf. Sao Paulo/Congonhas

c. Sao Paulo/Guarulhos (GRU): Primary airport emerged through the construction of a new airport

Sao Paulo/Guarulhos is located 14 miles from the center of the city of Sao Paulo. It was constructed in 1985 as a result of congestion and limitations of Sao Paulo/Congonhas[2].

Identification of a need to build a new airport: cf. Sao Paulo/Congonhas

Planning, Financing and Construction of new airport: It was constructed in 1985.

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[1] Source: Viracopos/Campinas International Airport website, available at; http://www.infraero.gov.br/usa/aero_prev_home.php?ai=215, last accessed; April 2008

[2] Source: Flight Global,*" Breaking point: Brazil's air traffic growth puts pressure on infrastructure",* available at: http://www.flightglobal.com/articles/2007/11/16/219612/breaking-point-brazils-air-traffic-growth-puts-pressure-on.html, last accessed; April 2008.

Transfer of traffic/Entry of carriers: International flights were transferred from Sao Paulo/Congonhas to Sao Paulo/Guarulhos in 1985.

Congestion of primary airports and limitations of existing airports: cf. Sao Paulo/Congonhas.

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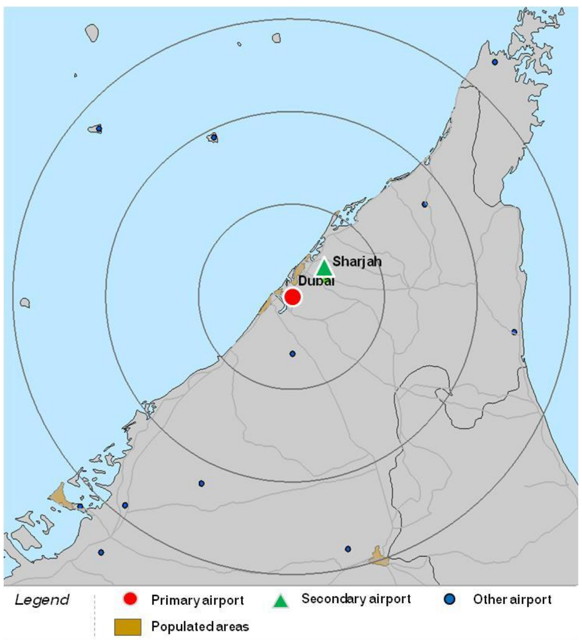
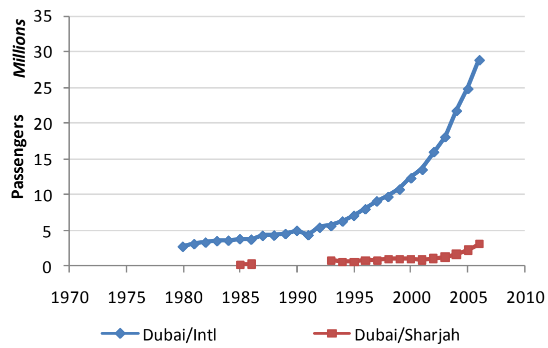
Appendix C-39: Middle East - Dubai (United Arab Emirates)

The multi-airport system that serves the Dubai metropolitan region is composed of one primary airport; Dubai/Intl (DXB-OMDB) and one secondary airport; Dubai/Sharjah (SHJ-OMSJ). The region has also one new high capacity airport that is under construction; Dubai World Central International Airport.





a. Dubai/Intl (DXB): Original airport (primary)

Dubai/Intl is located 4 miles from the center of the city of Dubai. It was built in 1959 and started operations in 1960. It has since that time being the primary airport in the metropolitan region[1].

b. Dubai/Sharjah (SHJ): Emerged secondary airport

Dubai/Sharjah is located 13 miles from the center of the city of Dubai. It was built in 1977 and was used in the 1980s as a cargo airport[2].

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[1] Source: Airport Technology website, *"Dubai International Airport (DXB/OMDB), United Arab Emirates"*, available at: http://www.airport-technology.com/projects/dubai/, last accessed; April 2008.

[2] Source: Sharjah International Airport website; available at: http://www.shj-airport.gov.ae/milestones.htm, last accessed; April 2008.

Entry of carriers (e.g. low-cost carriers): The airport emerged as a secondary airport in the metropolitan region with the entry and growth of Air Arabia (i.e. low-cost carrier in the Middle East) in 2003.

Presence of secondary basins of population: The airport is located close to Dubai and serves the primary basin of population.

c. Dubai World Central International Airport (JXB): New airport

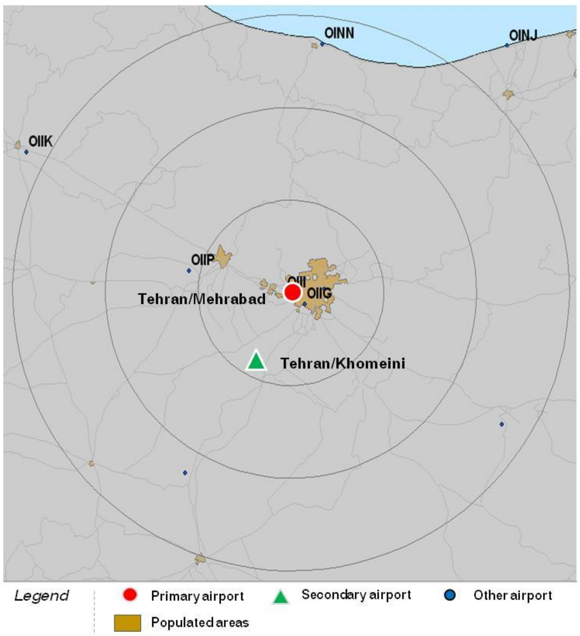
Dubai World Central International Airport, which under construction, is located south of the city of Dubai. It is expected to be completed by 2010.

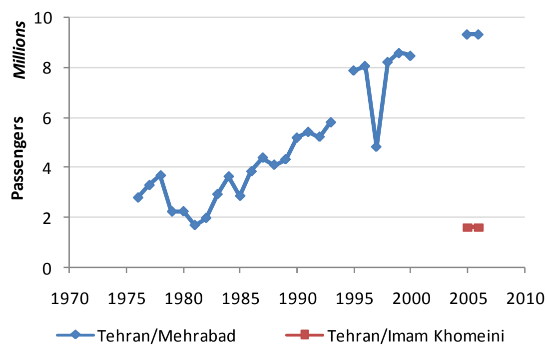
Forecast of future passenger traffic within the metropolitan region & identification of a need to build a new airport: Given the impressive historical growth rates of passenger traffic in the region, and the assumption that these rates will remain, the existing primary airport will not be able to accommodate forecasted demand.

Transfer of traffic/Entry of carriers: Both airports are expected to remain operative.

Appendix C-40: Middle East - Tehran (Iran)

The multi-airport system that serves the metropolitan region of Tehran is composed of one primary airport; Tehran/Mehrabad (THR-OIII) (i.e. the original airport) and one secondary airport; Tehran/Imam Khomeini (IKA-OIIE).





a. Tehran/Mehrabad (THR): Original primary airport

Tehran/Mehrabad is located 6 miles from the center of Tehran. It was historically the primary airport in the region before Tehran/Imam Khomeini (IKA) was built in 2004. International traffic was partially transferred from Tehran/Mehrabad Tehran/Imam Khomeini in 2004 and 2005. In 2006, Tehran/Mehrabad served 9.8 million passengers against 1.6 million for Tehran/Imam Khomeini[1]. Despite the gradual transfer of traffic to Tehran/Imam Khomeini, Tehran/Mehrabad remains the primary airport in the region.

Congestion of primary airports and limitations of existing airports: Due to urban development around Tehran/Mehrabad expansion capabilities were limited. In 1996, the Iranian Civil Aviation Organization (CAO) recognized that Mehrabad could not be

[1] Source: Abuel-Ealeh, S., *"A study of the market for intra-regional air services in the Middle East"*, Cranfield University, School of Engineering, Cranfield College of Aeronautics, MSc. Thesis, September 2007, available at: http://dspace.lib.cranfield.ac.uk:8080/handle/1826/2125, last accessed; April 2008.

upgraded and expanded with reasonable economy to meet the expected growth levels projected for the metropolitan region[1].

b. Tehran/Imam Khomeini (IKA): Airport emerged through the construction of a new airport

Tehran/Imam Khomeini is located 24 miles from the center of Tehran. Its construction was achieved in 2004 and was intended to serve as primary airport replacing Tehran/Mehrabad.

Tehran/Imam Khomeini was a secondary airport (based on 2006 traffic) figures. However, additional traffic was transferred from Tehran/Mehrabad in traffic in 2007 and Tehran/Imam Khomeini.

Identification of a need to build a new airport: cf. Limitations of Tehran/Mehrabad.

Planning, Financing and Construction of new airport: Tehran/Imam Khomeini (owned and operated by Turkish and Austrian TAV group was awarded under the Build Operate and Transfer (BOT) contract[2]. It was constructed over a 15,000 ha area which leaves space for future expansion. Construction began in 1994 and was completed in 2004. The initial phase of development of Tehran/Imam Khomeini has a capacity of 6.5 million passengers (2.5 million international and 4 million domestic). There are plans to later expand the capacity to 40 million passengers a year[3].

Transfer of traffic/Entry of carriers: Tehran/Imam Khomeini was opened in May 2004 and immediately closed because two Iranian airlines refused to switch to an airport run by foreigners (Turkish and Austrian TAV group) arguing security problems. Since then,

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[1] Source: Airport Technology website, *"Imam Khomeini International Airport (OIIE), Tehran, Iran"*, available at: http://www.airport-technology.com/projects/tehran/, last accessed; April 2008.
[2] Source: Airport Technology website, *"Imam Khomeini International Airport (OIIE), Tehran, Iran"*, available at: http://www.airport-technology.com/projects/tehran/, last accessed; April 2008.
[3] Ibid.

TAV officials were forced to clear out personnel and equipment and return control of the airport and the Turkish part of consortium was excluded[1].

Congestion of primary airports and limitations of existing airports: cf. Tehran/Mehrabad

Role of ownership and management of airports: Tehran/Mehrabad is owned and operated by Iran Airports Company which is an independent Airport Authority (fully owned by the local government). Unlike Tehran/Mehrabad, Tehran/Imam Khomeini was owned and operated by Turkish and Austrian TAV group (privately-owned and operated as an independent airport authority)[2]. In 2004, the operations were transferred to Iran Air[3]. The case of the Tehran multi-airport system illustrate some of the problems (i.e. securing return on investment and control over the entity for the duration of the contract) with the privatization of airports with stakeholders across different countries.

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[1] Ibid.
[2] Source: Airport Technology website, *"Imam Khomeini International Airport (OIIE), Tehran, Iran"*, available at: http://www.airport-technology.com/projects/tehran/, last accessed; April 2008.
[3] Ibid.

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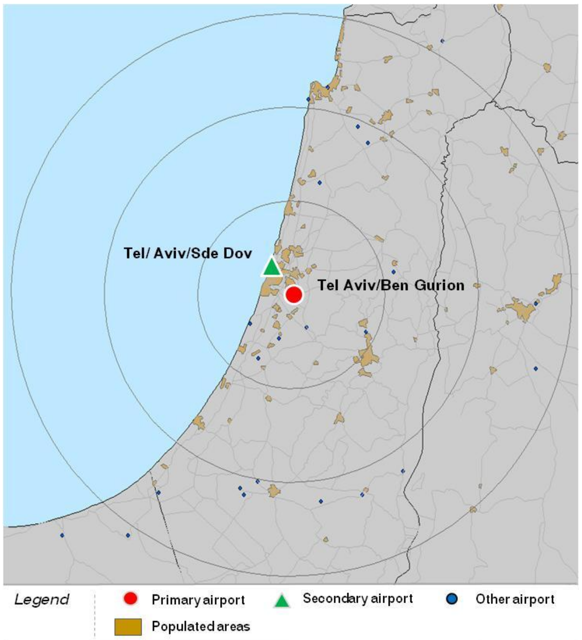
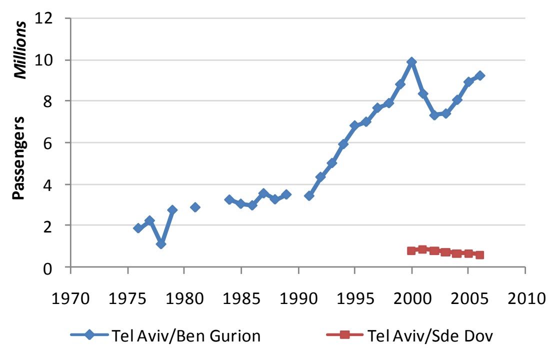
Appendix C-41: Middle East - Tel Aviv (Israel)

The multi-airport system that serves the Tel Aviv region is composed of one primary airport; Tel Aviv/Ben Gurion (TLV-LLBG) and one secondary airport; Tel Aviv/Sde Dov (SDV-LLSD).





a. Tel Aviv/Ben Gurion (TLV): Original airport (primary)

Tel Aviv/Ben Gurion is located 7 miles from the center of the city of Tel Aviv. It was built in 1936. The airport has historically been the primary airport in the region[1].

b. Tel Aviv/Sde Dov (SDV): Original airport (secondary)

Tel Aviv/Sde Dov is located 4 miles north west of the center of the city of Tel Aviv. It was built in 1937. In the 1940s, the airport was used as military base. Due to its location close to the sea and surrounded by urban development its expansion was limited. Several expansion projects were proposed in the 1970s and 1980s, however high costs and opposition from local communities blocked these projects. Given the access

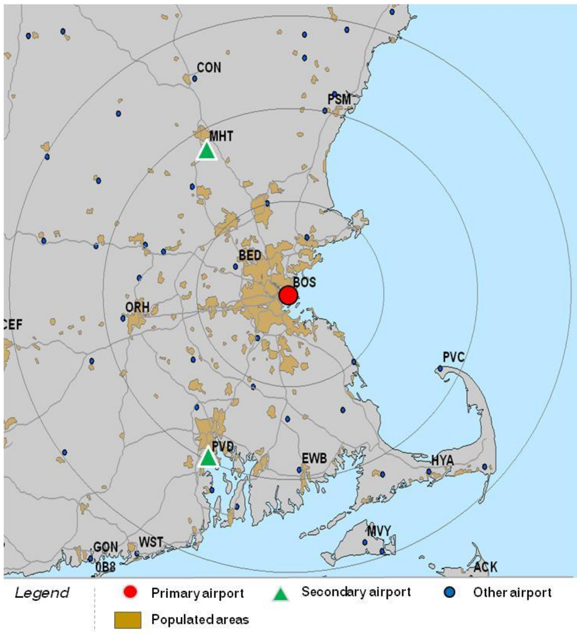
[1] Source: Israel Airports Authority, *"Ben Gurion - About the Airport – History"*, available at: http://www.iaa.gov.il/Rashat/en-US/Airports/BenGurion/AbouttheAirport/History/, last accessed; April 2008.

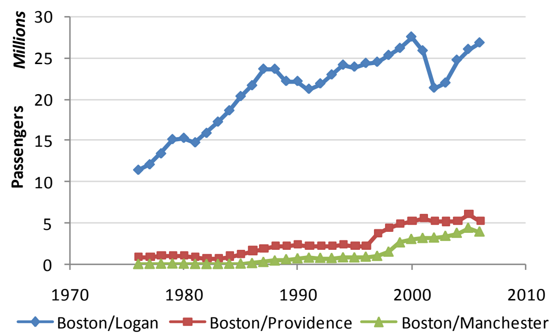
constraints (i.e. runway length; the single runway in 2007 was 5,700 ft long), the airport was used by turboprop aircraft serving domestic traffic.

Potential closure of the airport: Due to its key location, the value of the land on which the airport is located has significant increased. In 2007, a draft agreement was reached to close the airport and replace it by residential housing development at a cost of some $2 billion. The agreement is still subject to approval by an assembly of the landowners and the government offices affected by the issue. The commercial flights will be relocated to the primary airport; Ben Gurion and the military base will be transferred to another airport in the region (i.e. Palmachim Airbase).

Appendix C-42: North America - Boston (United States)

The multi-airport serving the Boston metropolitan region is composed of one primary airport; Boston/Logan (BOS-KBOS) and two secondary airports; Boston/Providence (PVD-KPVD) and Boston/Manchester (MHT-KMHT).





a. Boston/Logan (BOS): Original airport (primary)

Boston/Logan[1] has historically been the primary airport in the region. It opened on 1923 as the result of a funding campaign led by the local business community interested in developing the airport for air mail services. At its beginning, Boston/Logan was also used by the Massachusetts Air Guard and the Army Air Corps. It offered its first scheduled commercial passenger flights in 1927 between the cities of Boston and New York. In 1941, Boston/Logan's airside land area was expanded by 1,800 acres by the further filling of Boston Harbor. Additional runways, apron areas and three new hangars were built.

In the 1950s the airport received several infrastructure improvements such as loop access roadway system, runways and gates.

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[1] Source: Massport Logan Airport website, *"Logan International Airport: Then and Now*", available at: http://www.massport.com/Logan/about_histo.html, last accessed; April 2008.

In the 1960s, the airport received major improvements including the construction of the International Terminal, extension of runway 15R/33L, to accommodate the movement toward larger aircraft.

In the 1970s, major improvements continued with a new 285 foot control tower in 1973, a new terminal (Terminal E) and additional land fill of 234 acres allowing the construction of cargo and other facilities[1].

After several decades of continuous expansion, the 1980s were time for addressing environmental concerns with the soundproofing of classrooms in East Boston in addition to thousands of homes.

In the 1990s improvements of the airport focused on increasing Logan's efficiency without expanding the airport's borders or compromising on environmental benefits for its neighbors by performing several improvements.

Boston/Logan received an additional runway (14/32) in 2007.This runway was part of the OEP improvements that improve Logan’s capacity in North West wind conditions.

Congestion of primary airports: In the 1990s, Boston/Logan exhibited high level of delays and was repeatedly in the top 5 most delayed airports in the United States. High delays at Boston/Logan and the associated externalities made other airports in the region more attractive.

Airport development constraints: Boston/Logan has a highly constrained footprint. The airport land footprint is mostly the result of land reclaimed from the bay of Boston (towards the south part of the airport). On the north side, major roads and residential areas limit any expansion. The only recent major airside infrastructure improvement was the construction of the runway (14/32) which took approximately over 30 years to complete.

Environmental barriers and constraints: Major environmental barriers to the development and expansion of the airport arise from surrounding communities’ pressure.

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[1] Source: Airport Technology website, *“Logan International Airport Expansion, Boston, Massachusetts, USA”*, available at: http://www.airport-technology.com/projects/boston-logan/, last accessed; April 2008.

The delays that impacted the development of runway 14/32 were an illustration of the strong opposition from local communities. These community groups used environmental arguments (i.e. noise and local air pollution) to block the development process.

b. Boston/Providence (PVD): Emerged secondary airport

Boston/Providence[1] is located 46 miles south-west of Boston. It was dedicated in 1931.

Entry of carriers (e.g. low-cost carriers): In 1996, Southwest entered service at Boston/Providence, leading to significant growth in passenger traffic. Other airlines followed the entry of Southwest (i.e. Northwest, Continental, Delta, American Eagle, Air Canada).

Changes of airport status; conversion from military to civil status: Boston/Providence was originally a civil airport and was temporally used as an Army Air Base and a training base for officers World War II. In 1945, Boston/Providence was returned to the state of Rhode Island.

Upgrade of airport infrastructure: In the 1960s, significant improvements were performed. A new airport terminal opened and runways were expanded. In 1993, the Rhode Island Airport Corporation (RIAC) was created replacing the Division of Airports, a public agency, fully owned and operated by the State of Rhode Island. Additional infrastructure improvements were made to Boston/Providence in 1995 with the construction of the current airport terminal.

Presence of secondary basins of population: Boston/Providence is located 7 miles from Providence (RI). Providence represents a strong secondary basin of population in the region. In 2004, the urban area of Providence had a population of 1,174,548 (UN 2004).

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[1] Source: Providence Airport website, available at: http://www.pvdairport.com/riac/history.htm, last accessed: April 2008.

Congestion of primary airports: cf. Logan Airport

Role of ownership and management of airports: Boston/Providence is owned by the State of Rhode Island and operated by the Rhode Island Airport Corp.

c. Boston/Manchester (MHT): Emerged secondary airport

Boston/Manchester is located 43 miles north-west of Boston. It was dedicated in 1927.

Entry of carriers (e.g. low-cost carriers): Passenger traffic at Boston/Manchester remained very weak until the late 1990s. Southwest started to offer scheduled service at Boston/Manchester in 1998. This triggered the emergence of the airport as a successful secondary airport in the region. Several other carriers followed the entry of Southwest (i.e. American, ACA, Continental Express, and Northwest Airlines)

Changes of airport status; conversion from military to civil status: N/A (during World War II, the airport played an important role as a pilot training base).

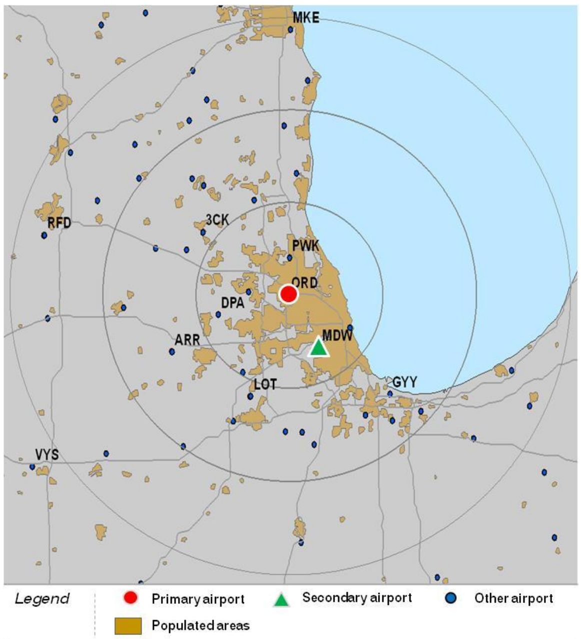
Presence of secondary basins of population: Boston/Manchester is located 4 miles from the city center of Manchester (NH). Similarly to Providence (RI), Manchester represents a secondary basin of population in the Boston region. In 2004, the urban area of Manchester had a population of 143,549 (UN 2004).

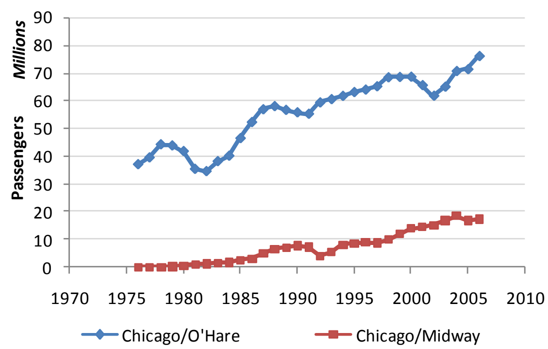
Congestion of primary airports: cf. Boston/Logan

Role of ownership and management of airports: Boston/Manchester is owned by the City of Manchester and operated by the City of Manchester.

Appendix C-43: North America - Chicago (United States)

The multi-airport system serving the Chicago metropolitan region is composed of one primary airport; Chicago/O'Hare (ORD-KORD) and one secondary airport; Chicago/Midway (MDW-KMDW).





a. Chicago/O'Hare (ORD): Primary airport emerged through the construction of a new airport

Chicago/O'Hare is located 16 miles from the center of the city of Chicago. The airport was constructed in 1942 as Douglas aircraft manufacturing plant during World War II. The site was chosen for its proximity to the city and transportation. Douglas Aircraft Company's contract ended in 1945. Chicago/Midway which is located closer to the City of Chicago center was the original primary airport serving the metropolitan region.

Congestion of primary airports: (Phase 1; Chicago/Midway constrained) In the mid 1940s, Chicago/Midway reached saturation. In the 1950s, it was also constrained by its short runways. Those prohibited the first generation of jet airplanes to access the airport. At the same time the City of Chicago and FAA began to develop Chicago/O'Hare as the next primary airport in the region.

(Phase 2; Chicago/O'Hare constrained[1]) Chicago/O'Hare exhibited high level of delays in 2003. According to the 2003 Airport Capacity Demand / Demand Profiles report[2], the runway, apron and terminal of Chicago/O'Hare were "near saturated most of the day" in 2001.

In addition, the development of Chicago/Midway is constrained due to urban area encroachment. As a consequence, the need for additional capacity in the region is real. This need motivated the planning process of a new airport in Peotone, and is also the initiating factor of the potential emergence of Gary airport located south east of the region and that may become a new secondary airport in the metropolitan region.

Identification of a need to build a new airport: cf. Congestion of the Primary (Phase 1; Chicago/Midway constrained)

Planning, Financing and Construction of new airport: The first commercial passenger flights were started in 1955. The international terminal was built in 1958 and the airport was completed in 1962.

Transfer of traffic/Entry of carriers: The majority of domestic traffic moved from Chicago/Midway in 1962 at the completion of the airport.

Limitations of existing airports: cf. Chicago/Midway

b. Chicago/Midway (MDW): Original airport (secondary)

Chicago/Midway is located 7 miles from the center of the city of Chicago. It was built in the early 1920s. Before the emergence of Chicago/O'Hare as a primary airport in the region in 1962, Chicago/Midway held the position of the busiest airport in the world

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[1] Source: Airport Technology website, *"O'Hare International Airport (ORD/KORD), Chicago, IL, USA"*, available at: http://www.airport-technology.com/projects/chicago/, last accessed; April 2008.
[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

during three decades[1]. Constrained by its short runways leading to its inability to host the first generation of jets, Chicago/Midway was handicapped and could not compete with Chicago/O'Hare. In the 1960s and the 1970s passenger declined significantly, and ultimately reached less than 25,000 enplanements in 1977.

Entry of carriers (e.g. low-cost carriers): In 1979, Midway Airlines became the first major airline formed after deregulation. Together with Southwest Airlines, they are credited with revitalizing Chicago/Midway. Midway Airlines ceased operations in 1991. Southwest Airlines and American Trans Air quickly replaced Midway Airlines and the airport went through significant growth in the 1990s.

Presence of secondary basins of population: This secondary airport is located closer to the primary basin of population than the primary airport due to historical reasons (i.e. original primary airport that lost its role after the emergence of Chicago/O'Hare).

[1] Source: Airport Technology website, *"Chicago Midway International Airport (MDW/KMDW), IL, USA"*, available at: http://www.airport-technology.com/projects/midway/, last accessed; April 2008.

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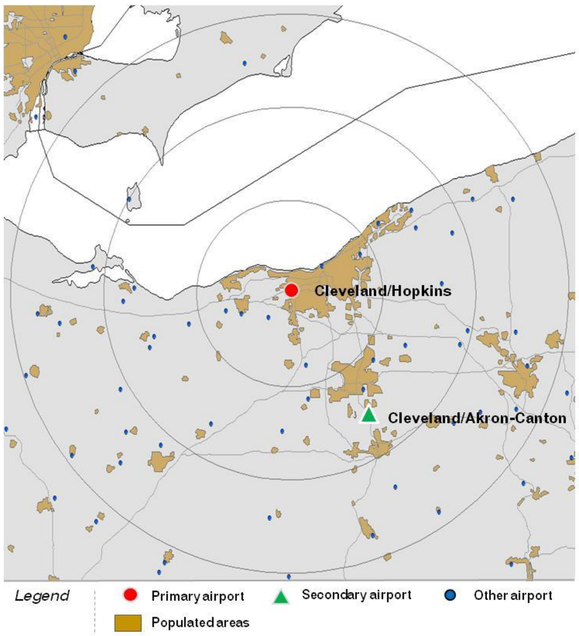
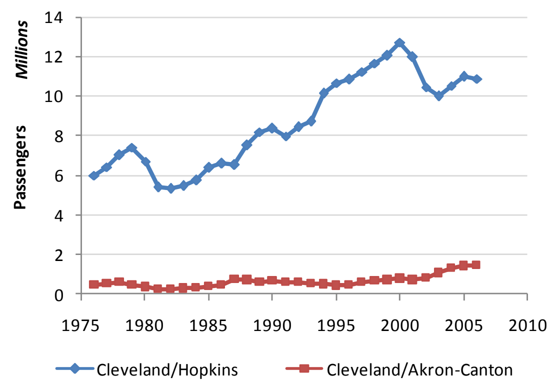
Appendix C-44: North America - Cleveland (United States)

The multi-airport system that serves the Cleveland metropolitan region is composed of one primary airport; Cleveland/Hopkins (CLE-KCLE) and one secondary airport; Cleveland/Akron-Canton (CAK-KCAK).





a. Cleveland/Hopkins (CLE): Original airport (Primary)

Cleveland/Hopkins is located 9 miles from the city of Cleveland. It was opened in 1925 and was the first municipally-owned commercial airport in the United States at the time[1]. It has historically been the primary airport in the metropolitan region.

b. Cleveland/Akron-Canton (CAK): Secondary airport

Cleveland/Akron-Canton is located 44 miles from the city of Cleveland. It was built in 1946. It is jointly operated by Summit County and Stark County.

Entry of carriers (e.g. low-cost carriers): Between 2004 and 2006, Cleveland/Akron-Canton exhibited significant growth mostly due to the entry and growth of AirTran Airways[1].

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[1] Source: Cleveland Hopkins International Airport website, *"Airport History"*, available at: http://www.clevelandairport.com/site/413/default.aspx, last accessed; May 2008.

Presence of secondary basins of population: Cleveland/Akron-Canton is located 12 miles from the city of Akron (OH) which represents a secondary basin of population in the Cleveland metropolitan region. In 2000, the city of Akron had a population of 217,000 and 695,000 for its metro area.

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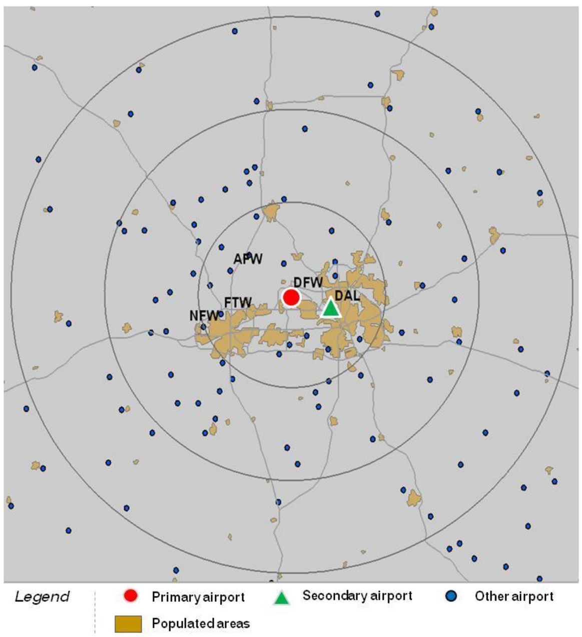
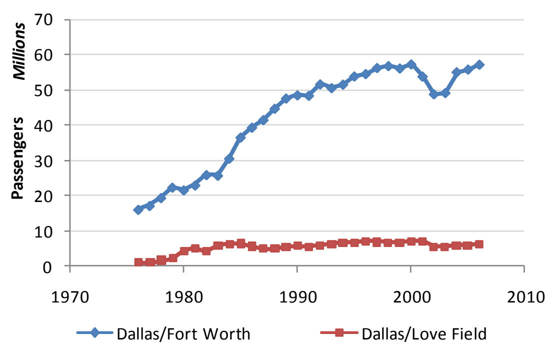
[1] Source: Akron-Canton Airport website, "*Akron-Canton Airport Achieves Fourth Consecutive Annual Passenger Record",* available at: http://www.akroncantonairport.com/news-detail.php?pageid=52&newscategoryid=1&newsid=5, released January 19, 2006, last accessed; May 2008.

Appendix C-45: North America - Dallas (United States)

The multi-airport system that serves the Dallas metropolitan region is composed of one primary airport; Dallas/Fort Worth (DFW–KDFW) and one secondary airport; Dallas/Love Field (DAL–KDAL). This latter airport was the original primary airport in the region before Dallas/Fort Worth was built in the 1960s. Due to capacity constraints and expansion constraints, Dallas/Fort Worth was built and commercial traffic was transferred from Dallas/Love Field to Dallas/Fort Worth.





c. Dallas/Love Field (DAL): Original airport (secondary)

Dallas/Love Field is located 5 miles from the center of the city of Dallas. It was built in 1917 and opened to civilian use in 1927. The airport remained Dallas primary airport until the opening of Dallas/Fort Worth in 1974 after both cities agreed on the location of a common airport in the 1960s.

Entry of carriers (e.g. low-cost carriers): Due to its better location than Dallas/Fort Worth, Dallas/Love Field remained competitive even with its limited infrastructure. Southwest airlines, founded in 1971, exploited the location advantage of Dallas/Love Field by offering short haul services between Dallas, Houston, and San Antonio. In 1973, Southwest Airlines managed to remain at Dallas/Love Field after it was granted by the courts the right to continue to operate intrastate service out of Dallas/Love Field.

After the opening of Dallas/Fort Worth, Southwest Airlines was the only carrier operating at Dallas/Love Field. After 1978, Southwest Airlines had plans to start offering flights to destination outside the state of Texas.

Presence of secondary basins of population: Similarly to the case of Chicago/O'Hare and Houston/Hobby, this secondary airport is located closer to the primary basin of population than the primary airport due to historical reasons (i.e. original primary airport that lost its role after the emergence of Chicago/O'Hare).

Congestion of primary airports: In the 1970s, the attractiveness of Dallas/Love Field was due mostly to its location (close to the center of the city of Dallas). It is becoming even more attractive as Dallas/Fort Worth is reaching capacity. According to the 2003 Airport Capacity Demand / Demand Profiles report[1], the runway, apron and terminal of Dallas/Fort Worth were "near saturated during peak hours" in 2001.

Role of regulatory and political factors: In order to keep Dallas/Fort Worth attractive by limiting the competition with Dallas/Love Field, Congressman Wright from Fort Worth, helped pass a law in Congress that restricted air service at Dallas/Love Field. The Wright Amendment restricted flights out of Dallas/Love Field to destinations in four neighboring states; Louisiana, Arkansas, Oklahoma, and New Mexico. Southwest continued to grow by offering flights that complied with the Wright Amendment. As a result of Southwest Airlines success, other airlines showed their interest in providing service out of Dallas/Love Field. In 1985, court battles were started over the interpretation of the Wright Amendment. In 1997, the Shelby Amendment successfully passed through Congress, which amended the Wright Amendment. It extended the number of neighboring states accessible from Dallas/Love Field from four to seven, adding Kansas, Mississippi and Alabama. In 1998, Continental Express became the first major airline other than Southwest to fly out of Dallas/Love Field since 1974. American Airlines followed the entry of Continental but was still battling against the Shelby Amendment, in order to restrict traffic out of Dallas/Love Field and keep Dallas/Fort Worth competitive.

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[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

d. Dallas/Fort Worth (DFW): Primary airport emerged through the construction of a new airport

Dallas/Fort Worth[1] is located between the cities of Dallas and Fort Worth, 16 miles from the center of the city of Dallas.

Identification of a need to build a new airport: Due to capacity constraints and expansion constraints at Dallas/Love Field, Dallas/Fort Worth was built and commercial traffic was transferred from Dallas/Love Field to Dallas/Fort Worth.

Planning, Financing and Construction of new airport: The land for Dallas/Fort Worth was purchased in 1966. Construction began in 1969 and it opened for commercial service in January 1974.

Transfer of traffic/Entry of carriers: In 1979, the Wright Amendment was passed. Its purpose was to transfer all remaining long-distance flights from Dallas/Love Field to Dallas/Fort Worth by banning those flights from Dallas/Love Field. In the early 1980s, Dallas/Fort Worth became a major hub for American Airlines and Delta Airlines. In the late 1980s, the airport authority announced plans to rebuild the existing terminals and construct two new runways.

Congestion of primary airports: Due to capacity constraints and expansion constraints at Dallas/Love Field, Dallas/Fort Worth was built and commercial traffic was transferred from Dallas/Love Field to Dallas/Fort Worth.

Limitations of existing airports: cf. Dallas/Love Field

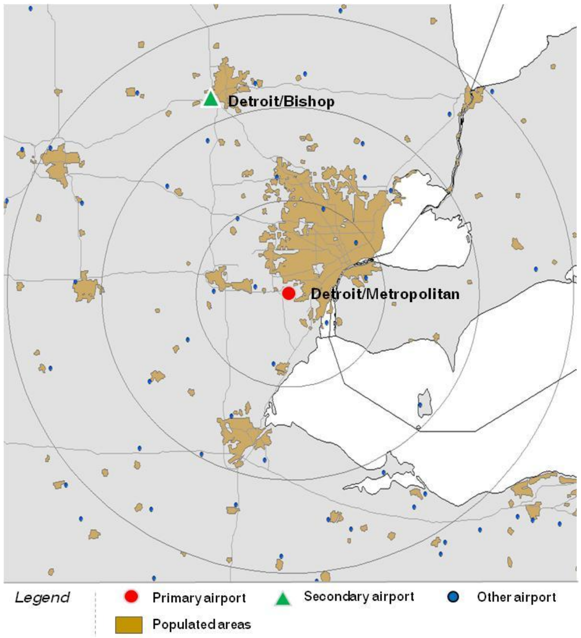
Role of regulatory and political factors: The origins of a common airport between the two cities can be traced back to 1927, when a first attempt to build a common airport failed. Other attempts were made in the 1940s but eventually failed because of

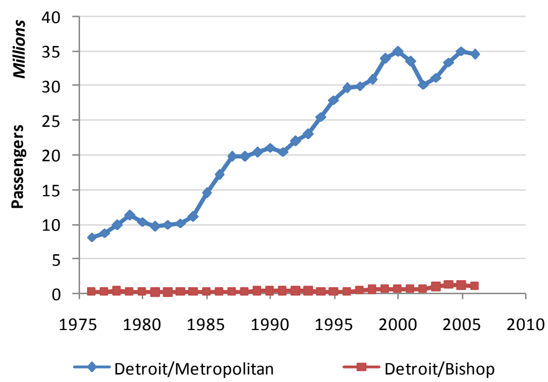
[1] Source: Airport Technology website, *"Dallas/Fort Worth International Airport (DFW/KDFW), TX, USA"*, available at: http://www.airport-technology.com/projects/dallas/, last accessed; April 2008

disagreements over its construction. Due to both the refusal of the FAA to invest in separate airport and the congestion of Dallas/Love Field, Dallas and Fort Worth cities agreed on the location (between the two cities) of a common airport.

Appendix C-46: North America - Detroit (United States)

The multi-airport system that serves the Detroit metropolitan region is composed of one primary airport; Detroit/Metropolitan (DTW-KDTW) and one secondary airport; Detroit/Bishop (FNT-KFNT).





a. Detroit/Metropolitan (DTW): Original primary airport

Detroit/Metropolitan is located 17 miles from the city of Detroit. It was built and opened in 1929. It has historically been the primary airport in the metropolitan region.

b. Detroit/Bishop (FNT): Secondary airport

Detroit/Bishop is located 54 miles from the city of Detroit.

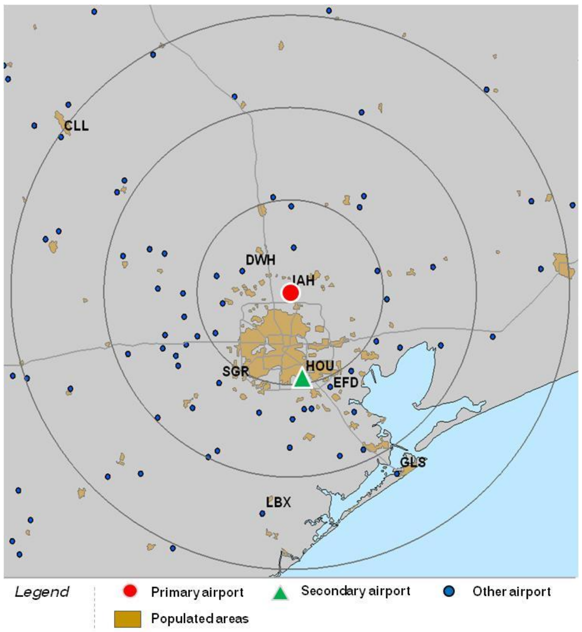
Entry of carriers (e.g. low-cost carriers): Passenger traffic at Detroit/Bishop increased after the entry of AirTran (i.e. low-cost carrier) in the early 2000s. It is also served by several network carriers; American Airlines, Continental Connection, Delta, Midwest and Northwest[1].

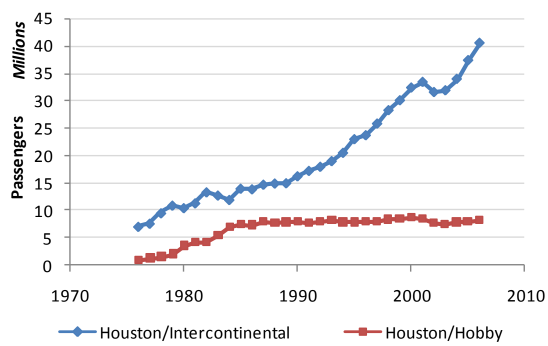
Presence of secondary basins of population: Detroit/Bishop is located 4 miles from the city of Flint which represents a secondary basin of population in the greater Detroit metropolitan region. In 2000, the city of Flint had a population of 125,000 and 444,000 for its metro area.

[1] Source: Bishop International Airport website, available at; http://www.bishopairport.org/, last accessed; May 2008.

Appendix C-47: North America - Houston (United States)

The multi-airport system that serves the Houston metropolitan region is composed of one primary airport; Houston/Intercontinental (IAH-KIAH) and one secondary airport; Houston/Hobby (HOU-KHOU). Houston/Hobby was the original primary airport in the region before the construction and transfer of traffic at Houston/Intercontinental in 1969.





a. Houston/Hobby (HOU): Original airport (secondary)

Houston/Hobby is located 9 miles from the center of the city of Houston. It was built in 1937. In the early 1940s, the airport's first concrete paved runways and taxiways were completed. Many airport facility improvements were made in the 1950s such as, terminal expansion, the reconstruction of runways 17/35, 4/22 and 13/31. After the construction of Houston/Intercontinental, in 1969, all commercial traffic was moved from Houston/Hobby to Houston/Intercontinental.

Entry of carriers (e.g. low-cost carriers): Houston/Hobby was reopened to commercial aviation in 1971 and Southwest initiated service with Dallas/Love Field. Several other airlines followed the entry of Southwest, including Braniff and Texas International Airlines.

Presence of secondary basins of population: Due to its location advantage Houston/Hobby has remained competitive with Houston/Intercontinental.

b. *Houston/Intercontinental (IAH): Primary airport emerged through the construction of a new airport*

Houston/Intercontinental is located 15 miles from the center of the city of Houston.

Identification of a need to build a new airport: In the 1960s, the construction of Houston/Intercontinental was motivated by the land limitations at Houston/Hobby, the first commercial airport in the region.

Planning, Financing and Construction of new airport: The airport was opened in 1969 as Houston/Intercontinental. All passenger air carriers moved from Houston/Hobby to the new airport. Originally, Terminals A and B were built. With the growth of traffic, new facilities were added in the 1980s and 1990s.

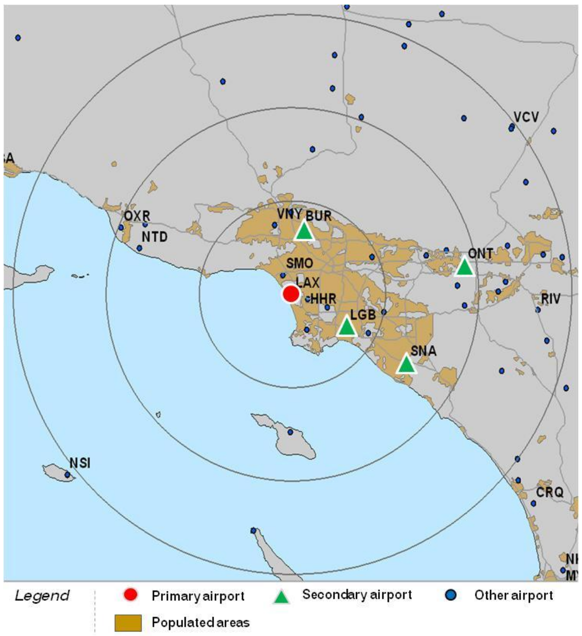
Transfer of traffic/Entry of carriers: The transfer of traffic from Houston/Hobby to Houston/Intercontinental was performed in 1969.

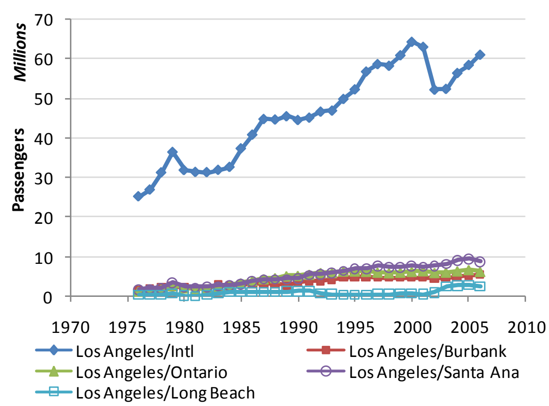
Congestion of primary airports: (Phase 1: Houston/Hobby constrained) By the end of the 1950s, even though runways were reconstructed, there was the need to lengthen them in order to host the first generation of jet aircraft.

Limitations of existing airports: cf. Houston/Hobby

Appendix C-48: North America - Los Angeles (United States)

The multi-airport system that serves the Los Angeles metropolitan region is composed of one primary airport; Los Angeles/Intl (LAX-KLAX) and four secondary airports; Los Angeles/Santa Ana (SNA-KSNA), Los Angeles/Ontario (ONT-KONT), Los Angeles/Burbank (BUR-KBUR) and Los Angeles/Long Beach (LGB-KLGB).





a. Los Angeles/Intl (LAX): Original airport (primary)

Los Angeles/Intl[1] is located 12 miles southwest of the center of Los Angeles. It was constructed in 1928 and opened in 1930. In the 1950s the airport was expanded westward towards the Pacific Ocean.

Congestion of primary airports: Los Angeles/Intl is constrained by capacity. According to the 2003 Airport Capacity Demand / Demand Profiles report[2], the runway, apron and terminal of Los Angeles/Intl were "near saturated at peak hours" in 2001. "Because of the airport's relatively urban setting any major expansion plans are always going to be met

[1] Source: Airport Technology website, *"Los Angeles International Airport (LAX/KLAX), CA, USA"*, available at: http://www.airport-technology.com/projects/losangeles/, last accessed; April 2008.
[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

with discontent and measured opposition. The airport authority initiated a master plan in 1994 and has been modifying it ever since"[1].

b. Los Angeles/Burbank (BUR): Emerged secondary airport

Bob Hope Airport is located 12 miles from the center of the city of Los Angeles. It was opened in 1930.

Entry of carriers (e.g. low-cost carriers): Airlines re-entered Los Angeles/Burbank in the 1960s when jet airliners capable of using the airport short runways were available. The entry of Southwest airlines in 1990 also stimulated passenger traffic.

Changes of airport status; conversion from military to civil status: (World War II only) In 1940, the airport was purchased by Lockheed who began expanding its facilities on land adjacent to the airport's runways in support of the war effort.

Presence of secondary basins of population: Los Angeles/Burbank is located 3 miles from the city center of Burbank (CA) which represents a secondary basin of population in the Greater Los Angeles Area. In 2004, the Burbank city had a population of 100,316 (UN 2004). Los Angeles/Burbank is in located in the same county at Los Angeles/Intl with total population 9,948,081 residents in 2006 (US Census).

Congestion of primary airports: cf. Los Angeles/Intl

c. Los Angeles/Ontario (ONT): Emerged secondary airport

Los Angeles/Ontario is located 37 miles east of the city of Los Angeles. It was built in 1923[2].

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[1] Source: Airport Technology website, *"Los Angeles International Airport (LAX/KLAX), CA, USA"*, available at: http://www.airport-technology.com/projects/losangeles/, last accessed; April 2008.
[2] Source: Los Angeles World Airports, *"LA/ Ontario International – Airport History"*, available at: http://www.lawa.org/ont/ontHistory.cfm, last accessed; April 2008.

Entry of carriers (e.g. low-cost carriers): Southwest airline started offering service in 1995.

Presence of secondary basins of population: Los Angeles/Ontario is located in the San Bernardino-Riverside-Ontario area also known as the inland empire. In 2000, this MSA (Metropolitan Statistical Area) was composed of 4,026,135 residents.

Congestion of primary airports: cf. Los Angeles/Intl

d. Los Angeles/Santa Ana (SNA): Emerged secondary airport

Los Angeles/Santa Ana, also known as John Wayne airport, is located 34 miles from the city of Los Angeles. It was built in the 1920s, as private airfield and became publicly owned in 1939. After serving as a military base during World War II, it was returned by the federal government to the County[1].

Entry of carriers (e.g. low-cost carriers): Southwest airlines started to offer service at Los Angeles/Santa Ana in 1994.

Upgrade of airport infrastructure: Improvements were made in the 1960s with the opening of a new terminal and that could accommodate 400,000 passengers annually. Several other improvements were made in the 1970s and 1980s.

Environmental constraints: In 1985, a Federal Court settlement was signed in order to formalize a consensus reached between the County of Orange and the local communities (i.e. County of Orange, the City of Newport Beach, the Airport Working Group (AWG), and Stop Polluting Our Newport (SPON)) on the nature and extent of airport improvements (i.e. limiting the capacity of the airport). In 2002, the 1985 settlement

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[1] Source: John Wayne Airport, *"Airport history"*, available at: http://www.ocair.com/newsandfacts/airporthistory.htm, last accessed; April 2008.

agreement was amended to allow an incremental increase in passenger traffic and daily operations.

Presence of secondary basins of population: Los Angeles/Santa Ana is located 4 miles from Santa Ana (population: 337,977) and 7 miles from Orange city (population: 128,821). Both cities are located Orange County which had 2,846,289 residents according to the 2000 US census.

Congestion of primary airports: cf. Los Angeles/Intl

e. Los Angeles/Long Beach (LGB): Emerged secondary airport

Los Angeles/Long Beach[1] is located 17 miles from the city of Los Angeles. It was built in the 1920s as a Naval Reserve Air Base (NRAB). In the 1970s, the airport was extensively used as an aircraft manufacturing location (i.e. Douglas).

Entry of carriers (e.g. low-cost carriers): Southwest airlines started offering scheduled service in 2002. JetBlue also offers schedule service at Los Angeles/Long Beach.

Environmental constraints: The low volume of passenger traffic at Los Angeles/Long Beach is mainly due to ordinances adopted to minimize noise in the residential neighborhoods surrounding the airport. In 1981, the City make first attempt to regulate airport-related noise by ordinance. In 1983, Alaska Airlines and other airlines sued the City over noise regulations. From 1984 through 1986, Long Beach residents filed lawsuits against City, asserting damage as result of aircraft noise from Los Angeles/Long Beach. The ordinance was invalidated by the District Court in 1988. In 1995, a settlement was reached by all parties that resulted in existing Noise Compatibility Ordinance. The access to the airport is currently limited to 41 slots are available each day for commercial

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[1] Source: Airport website history page, available at: http://www.longbeach.gov/airport/about/history_gallery.asp, last accessed; March 2008 and Long Beach Historical Timeline; available at: http://www.longbeach.gov/civica/filebank/blobdload.asp?BlobID=2999, last accessed; March 2008.

passengers' flights and cargo. As of March 7, 2003, the agreement between Los Angeles/Long Beach, and air carriers, stated the allocation of slots to carriers; Jet Blue (22), American (7), America West (5), Alaska (2), UPS (2), FedEx (2) and Airborne Express (1).

Presence of secondary basins of population: Los Angeles/Long Beach is located 3.9 miles from the city of Long Beach (population: 461,522) and 2.4 miles from the city of Lakewood (population: 88,253) which are both located in the Los Angeles county.

Congestion of primary airports: cf. Los Angeles/Intl

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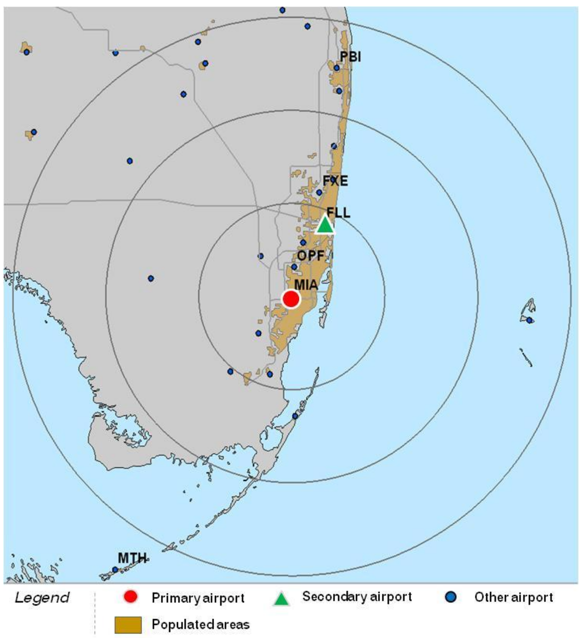
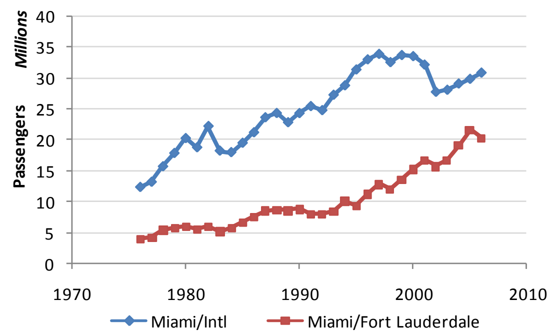
Appendix C-49: North America - Miami (United States)

The multi-airport system that serves the Miami metropolitan region is composed of two primary airports; Miami/Intl (MIA-KMIA) and Miami/Fort Lauderdale (FLL-KFLL). Miami/Intl is the original airport in the region. Miami/Fort Lauderdale emerged as a secondary airport from an under-utilized airport into a primary airport.





a. *Miami/Intl (MIA): Original airport (primary)*

Miami/Intl is located in 6 miles from the center of the city of Miami. The airport was constructed in 1928 and has been the major airport in the region since.

Congestion of primary airports: Miami airport is constrained by capacity[1]. According to the 2003 Airport Capacity Demand / Demand Profiles report[2], the runway, and terminal of Miami/Intl were "near saturated at peak hours" in 2001 and the apron was "new saturated most of the day".

[1] Source: Airport Technology website, *"Miami International Airport (MIA/KMIA), FL, USA"*, available at: http://www.airport-technology.com/projects/miami/, last accessed; April 2008.
[2] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

b. Miami/Fort Lauderdale (FLL): Primary airport

Miami/Fort Lauderdale is located 20 miles from the city of Miami. It opened in 1929.

Entry of carriers (e.g. low-cost carriers): The first commercial flights to Nassau began in 1953, and domestic flights began in 1958, operated by Eastern Airlines, National Airlines, and Northeast Airlines. Traffic at the airport grew slowly until the entries of Southwest Airlines in 1996. Several other low-cost carriers have followed the entry of Southwest; Spirit in 1999, JetBlue in 2001 and then Air Tran.

Changes of airport status; conversion from military to civil status: At the beginning of World War II, it was commissioned by the United States. The base was initially used for refitting civil airliners and was later used as a main training base for naval aviators. After the end of World War II, Broward County purchased the Naval Air Station in order to develop the airport as a commercial airport.

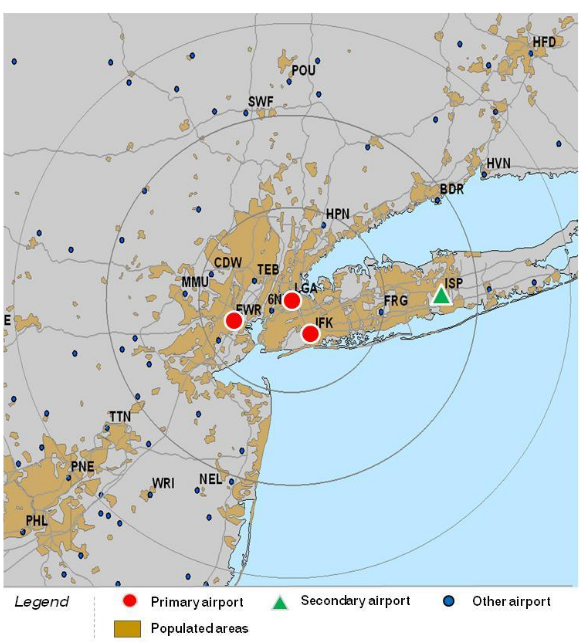
Presence of secondary basins of population: Miami/Fort Lauderdale is located 3.4 miles from the city center of Fort Lauderdale (FL) which represents a secondary basin of population in the Miami metropolitan region. In 2004, the Fort Lauderdale city had a population of 152,397 (UN 2004).

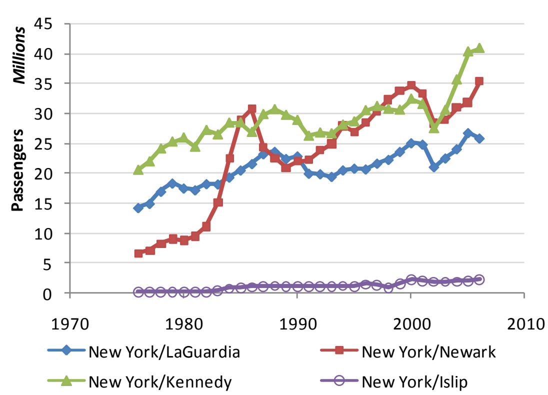
Congestion of primary airports: cf. Miami/Intl

Appendix C-50: North America - New York (United States)

The multi-airport system that serves the New York metropolitan region is composed of three primary airports; New York/LaGuardia (LGA-KLGA), New York/Newark (EWR-KEWR) and New York/Kennedy (JFK-KJFK) and one secondary airport; New York/Islip (ISP-KISP). It is one of the most complex and mature multi-airport system in the world.

In the 1920s, New York/Newark was the largest commercial airport in the metropolitan area. However, it was closed in 1939 as traffic decreased as a result of the opening of New York/LaGuardia. It was the only major commercial airport in the New-York metropolitan area until the emergence, in the early 1950s of New York/Kennedy. By the beginning of the 1980s, New York/Kennedy had reached its mature state. In the mid 1980s, the entry of a low-cost carrier (People Express) initiated the emergence of New York/Newark. In 1988, the failure of this airline created a significant decrease of traffic. However, the airport was in place and able, over the 1990s, to accommodate a significant fraction of the air transportation growth in the New York region. In 2000, New York/LaGuardia capacity crisis highlighted the overall capacity of the airport system was inadequate. In 2001, the entry of Southwest at New York/Islip (ISP) induced a significant increase of traffic at this airport. New York/Islip is the latest secondary airport in the regional airport system.





a. New York/LaGuardia (LGA): Original airport (primary)

New York/LaGuardia[1] is located 7 miles from the center of New York City. It was built in 1929 and opened to commercial service in 1939. During the 1960s, several improvements were made to the airport such as the construction of a new central terminal. The runways were also extended over water to 7,000 ft and 150 ft wide in 1967. The configuration of the airport did not significantly evolve since the 1960s and still features two runways of 7000 feet by 150 ft.

Congestion of primary airports: New York/LaGuardia is one of three slot restricted airport in the United States as of 2008. The airport is also constrained by a perimeter rule that established in 1969. As a consequence, the delays are maintained to lower levels than what they would be without demand management restrictions.

Role of ownership and management of airports: New York/LaGuardia is owned and operated by the Port Authority of New York and New Jersey (PANYNJ) which is a bi-state port district, established in 1921 and runs most of the regional transportation infrastructure, including the bridges, tunnels, airports, and seaports, within the New York–New Jersey Port District.

b. New York/Newark (EWR): Original airport (primary)

New York/Newark[2] is located 9 miles from the center of New York City. It was opened in 1928. It was the first primary airport in the metropolitan areas in the 1920s and 1930s until the opening of New York/LaGuardia in 1939. Traffic then shifted to New York/LaGuardia as New York/Newark was closed to passenger traffic and taken over by the United States Army Air Corps during World War II. The Port Authority of New York and New Jersey took over the airport in 1948. In the 1950s, major investments were performed including the opening of a new instrument runway, a new terminal building a

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[1] Source: Port Authority of New-York New Jersey website, *"LaGuardia, Facts & Information",* available at: http://www.panynj.gov/aviation/lhisfram.htm, last accessed; April 2008.

[2] Source: Port Authority of New-York New Jersey website, *"Newark Liberty, Facts & Information",* available at: http://www.panynj.gov/aviation/ehisfram.htm, last accessed; April 2008.

control tower and an air cargo center. The Central Terminal Area was constructed and opened in 1973. A new runway 4L/22R was built in 1970 and the previously existing runway 4-22 was rebuilt and renamed 4R-22L in 1973.

Entry of carriers (e.g. low-cost carriers): The airport remained underutilized in the 1970s, but the entry of People Express (i.e. one of the first U.S. low-cost carriers) in 1981 resulted in significant growth in passenger traffic and ultimately propelled the airport to the largest airport in the region in terms of passenger traffic, above New York/Kennedy and New York/LaGuardia.

Congestion of primary airports: New York/Newark is chronically exhibiting high level of delays as other primary airports in the New York region do.

c. New York/Kennedy (JFK): Primary airport emerged through the construction of a new airport

New York/Kennedy[1] is located 13 miles from the center of New York City. It was built in 1942. The airport was opened to commercial traffic 1948. Since 1948 the airport featured only one terminal until 1957 when a new international arrivals terminal was built. In the 1960s, several ground side improvements were made with the opening of eight new terminals. Terminal improvements are also underway since the end of the 1990s[2] [3].

Congestion of primary airports: In the recent years, New York/Kennedy has been exhibiting significant levels of delays and congestion (OPSNET 2008).

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[1] Source: Port Authority of New-York New Jersey website, *"John F. Kennedy, Facts & Information",* available at: http://www.panynj.gov/aviation/jhisfram.htm, last accessed; April 2008.
[2] Source: Airport Technology website, *"JFK International Airport JetBlue Terminal, New York, USA"*, available at: http://www.airport-technology.com/projects/jetbluet5/, last accessed; April 2008.
[3] Source: Airport Technology website, *"JFK International Airport (JFK/KJFK), New York, NY, USA"*, available at: http://www.airport-technology.com/projects/jfk/, last accessed; April 2008.

d. New York/Islip (ISP): Emerged secondary airport

New York/Islip is located in Islip, on Long Island. It is located 48 miles from the center of New York City.

Entry of carriers (e.g. low-cost carriers): Until 1999, the airport was only served with limited service by American Airlines and US Airways. In 1999, Southwest Airlines entered service at the airport and soon became the dominant carrier at this airport. In 2003, Southwest airlines represented about 80% of the airport market share in terms of movements.

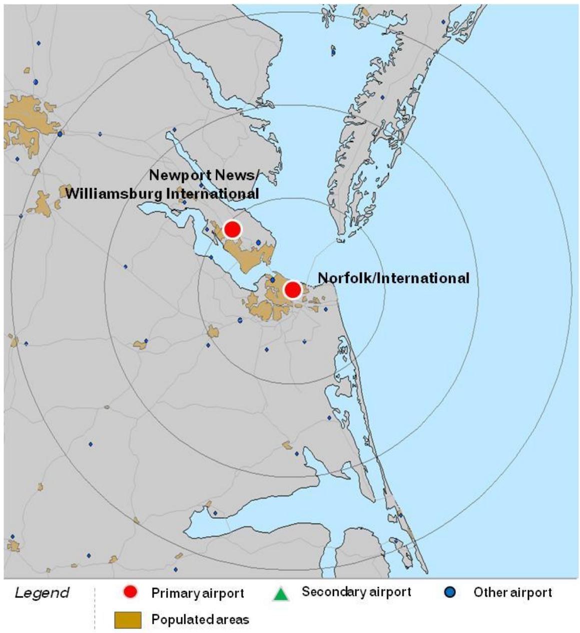
Presence of secondary basins of population: Long Island Mac Arthur airport is located 7 miles from the city of Islip (population: 322,612 US Census 2000) which are both located in the Suffolk county (population: 1,419,369 US Census 2000) which is covers most of Long Island.

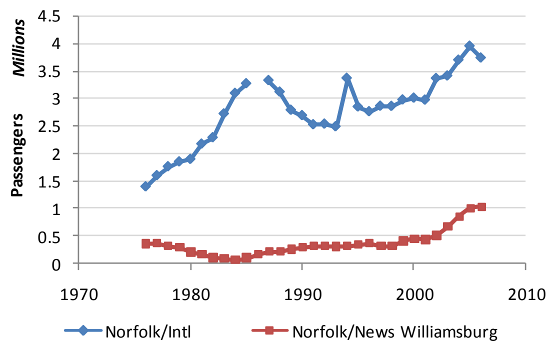
Congestion of primary airports: cf. New York/LaGuardia, New York/Kennedy and New York/Newark.

Role of ownership and management of airports: New York/Islip is owned and operated by the town of Islip.

Appendix C-51: North America - Norfolk (United States)

Norfolk multi-airport system is composed of two primary airports; Norfolk/Intl (ORF-KORF) and Norfolk/News Williamsburg (PHF-KPHF).





a. Norfolk/Intl (ORF): Original airport (primary)

Norfolk/Intl is located 4 miles from the center of the city of Norfolk. The airport was built in 1938.

b. Newport News/Williamsburg International (PHF): Primary airport

Norfolk/News Williamsburg is located 20 miles from the center of the city of Norfolk and miles from the city of Hampton.

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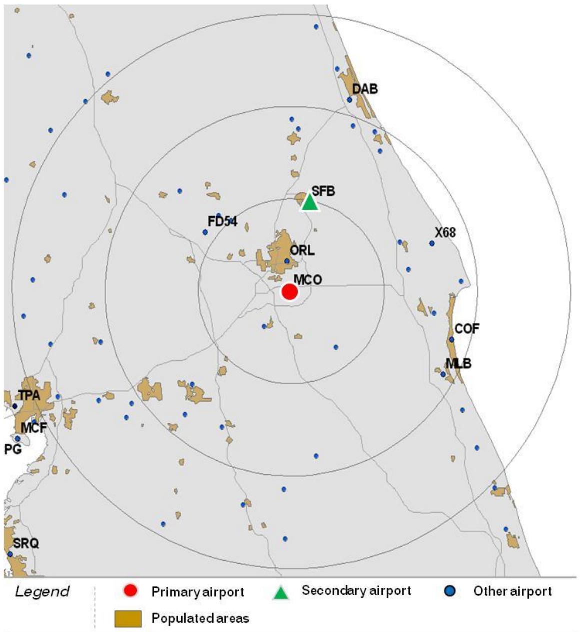
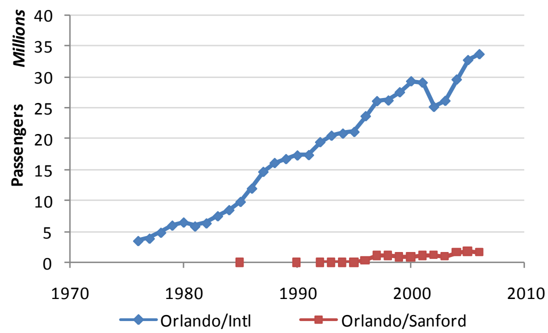
Appendix C-52: North America - Orlando (United States)

The multi-airport system that serves the Orlando region is composed of one primary airport; Orlando/Intl (MCO-KMCO) and one secondary airport; Orlando/Sanford (SFB-KSFB).





a. Orlando/Intl (MCO): Original airport (primary)

Orlando/Intl is located 8 miles from the center of the city of Orlando. Before 1974, it was an Air Force Base that closed in 1974. Delta airlines, Eastern Airlines, National Airlines, and Southern Airlines started offering scheduled service at Orlando/Intl in the 1970s. In 1983, several infrastructure improvements were made with the construction of the international concourse that opened a year later in 1984. In 1988, a Capacity Improvement Program was started. A third runway was opened in 1989 resulting in the increase of the capacity of the airport. In 1999, the approval for the construction of a fourth runway 17L/35R was received leading to the successful opening of the runway in 2003.

Congestion of primary airports: Orlando/Intl infrastructure had successfully received capacity improvements over the years and is not congested as other major airports in the United States. According to the 2003 Airport Capacity Demand / Demand Profiles report[1], the runway, apron and terminal of Orlando/Intl had "capacity available all day" in 2001.

b. Orlando/Sanford (SFB): Emerged secondary airport

Orlando/Sanford is located 18 miles from the center of the city of Orlando. It was built in the 1940s.

Changes of airport status; conversion from military to civil status: In 1942, the City of Sanford deeded the Airport to the U.S. Navy and the Airport became a Naval Air Station. After World War II, the Naval Air Station was decommissioned in 1946. The City of Sanford reacquired the land. After the Korean War began in 1951, the Navy once again acquired the airport. Orlando/Sanford operated as a training base for fighter, attack, and reconnaissance aircraft until it closed in June of 1968 and the City of Sanford reacquired Orlando/Sanford and took the operational control. In 1971, the Sanford Airport Authority was created and became responsible for its operation, maintenance, and development.

Upgrade of airport infrastructure: A master plan update was completed in 1995 and was revised in 1997 and that included the development of infrastructure such as, a main runway extension, the construction of an international arrivals building, taxiway improvements, and new navigation and approach systems.

Presence of secondary basins of population: Orlando/Sanford is located close to the city of Sanford, in the county of Seminole (i.e. population 365,196 in 2000[2]).

Congestion of primary airports: cf. Orlando/Intl

Role of ownership and management of airports: Orlando/Sanford is one owned by the Sanford Airport Authority and managed by TBI plc. (a private airport management group).

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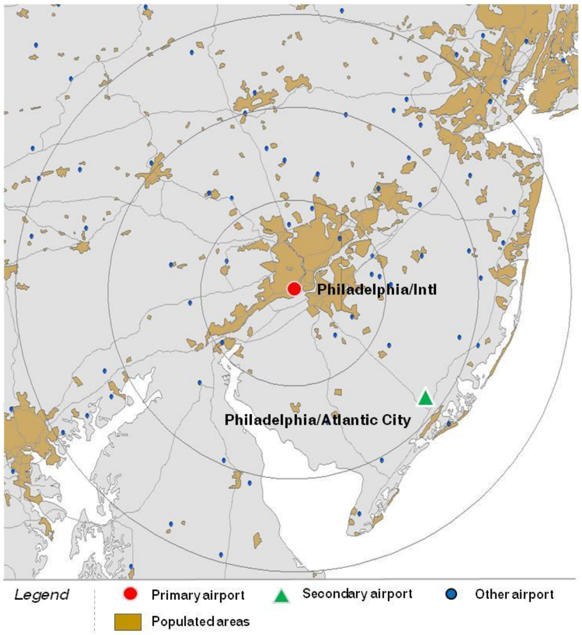
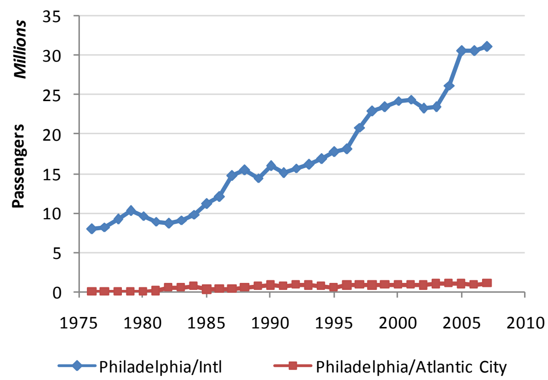
[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[2] Data source: U.S. Census data (2000).

Appendix C-53: North America - Philadelphia (United States)

The multi-airport system that serves the Philadelphia metropolitan region is composed of one primary airport; Philadelphia/Intl (PHL-KPHL) and one secondary airport; Philadelphia/Atlantic City (ACY-KACY).





a. Philadelphia/Intl (PHL): Original primary airport

Philadelphia/Intl is located 7 miles from the city of Philadelphia. It was opened in 1927 and has historically been the primary airport in the metropolitan region.

Congestion of primary airports: In 2005, Philadelphia/Intl was the fifth airport the highest delays in the United States with 27% of late arrivals. Congestion problems could be alleviated with the reconfiguration project that is underway. However the 2007 FAA Fact Study II showed that Philadelphia/Intl will need additional capacity in 2015, without planned improvements and even with after current planned improvements[1].

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[1] Source: FAA Capacity Needs in the National Airspace System: An Analysis of Airports and Metropolitan Area Demand and Operational Capacity in the Future, Washington, DC: U.S. Department of Transportation (DOT) Federal Aviation Administration (FAA), 2007.

b. Philadelphia/Atlantic City (ACY): Secondary airport

Philadelphia/Atlantic City is located 47 miles from the city of Philadelphia. It was established in 1942 as a Naval Air Station [1].

Entry of carriers (e.g. low-cost carriers): As of 2008, Philadelphia/Atlantic City was served by one low-cost carrier (i.e. Spirit Airlines).

Conversion from military airfield: In 1958, the lease was transferred to the FAA after the NAS Atlantic City was decommissioned. The property was sold to the federal government to provide a site for aviation test facilities[2].

Presence of secondary basins of population: Philadelphia/Atlantic City is located 9 miles from the center of Atlantic City (population of 41,000 and 271,000 for the metro area according to the 2000 Census). Atlantic City is also a tourist destination (e.g. casino and gambling industry).

Congestion of primary airports: cf. Philadelphia/Intl.

Role of ownership and management of airports: Philadelphia/Atlantic City is operated by AvPORTS, as successor to American Port Services under a Use and Occupancy Agreement with the South Jersey Transportation Authority (SJTA)[3].

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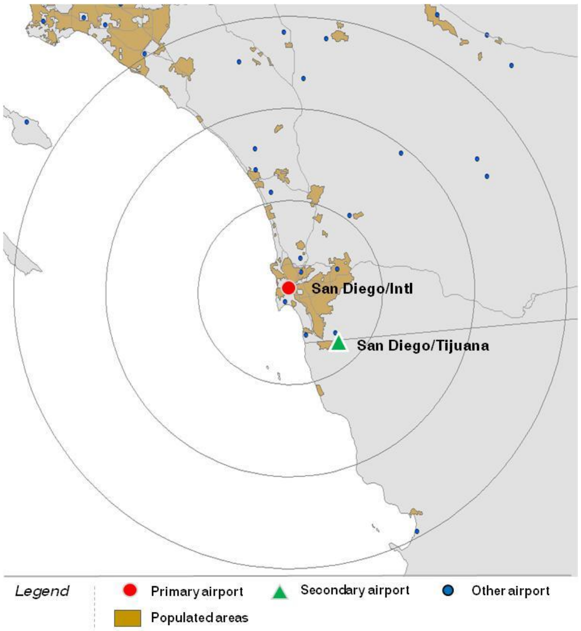
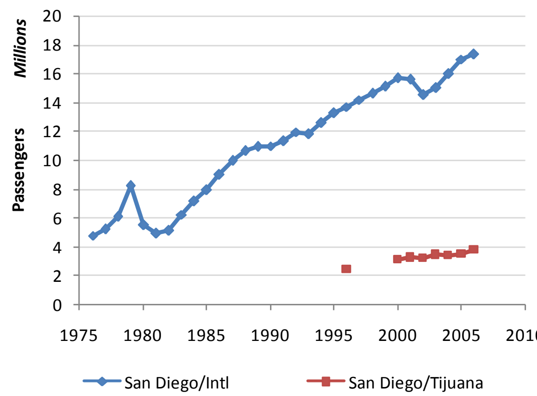
[1] Source: Atlantic City Airport website, *"Atlantic City International Airport Since 1942"*, available at: http://www2.sjta.com/acairport/history.asp, last accessed; May 2008.
[2] Ibid.
[3] Idid.

Appendix C-54: North America - San Diego (United States)

The multi-airport system that serves the Philadelphia metropolitan region is composed of one primary airport; San Diego/Intl (SAN-KSAN) and one secondary airport; San Diego/Tijuana (TIJ-MMTJ).





a. San Diego/Intl (SAN): Primary airport

San Diego/Intl is located 2 miles from San Diego. It was dedicated in 1928 and has historically been the primary airport in the metropolitan region. It is owned by the San Diego County Regional Airport Authority.

Congestion of primary airports: San Diego/Intl was the 30th airport with the highest delays in the United States (i.e. 20% of delayed arrivals)[1].

b. San Diego/Tijuana (TIJ): Secondary airport

San Diego/Tijuana is located 16 miles from San Diego. It was opened in 1970 [1].

[1] Data source: US Federal Aviation Administration (FAA), Aviation System Performance Metrics (ASPM), Airline Service Quality Performance (ASQP), available at: http://aspm.faa.gov/aspm/entryASPM.asp, last accessed; April 2008

Entry of carriers (e.g. low-cost carriers): In 2005, Avolar (i.e. a Mexican low-cost carrier) established a hub at San Diego/Tijuana. It is also served by other low-cost carriers; Interjet and Volaris. It is also served by Mexican network carrier Aeroméxico which also offers service to Asia (i.e. Tokyo-Narita and Shanghai) which is not available at San Diego/Intl.

Airport Expansion and Improvements: As of 2007, a plan to build a Cross Border Terminal at Tijuana International Airport was proposed[2]. This terminal would greatly improve the flow of passengers from the United States and ease the border crossing process.

Presence of secondary basins of population: San Diego/Tijuana is located 3 miles from the city center of Tijuana. In 2005, the city of Tijuana had a population of 1,286,000 and 4,923,000 for its metro area.

Congestion of primary airports: cf. San Diego/Intl.

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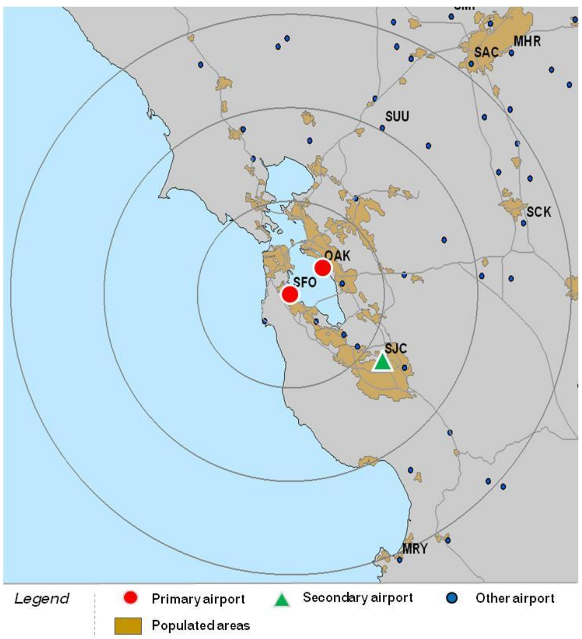
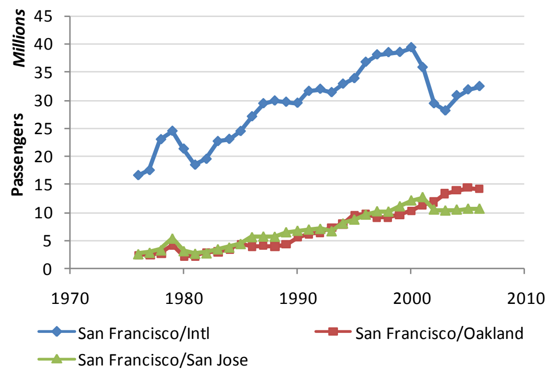
[1] Source: Tijuana airport website, available at: http://tijuana.aeropuertosgap.com.mx/index.php, last accessed; May 2008.

[2] San Diego Regional Chamber of Commerce's (SDRCC) website, *"Business Delegation Receives Support for Regional Projects in Mexico City"* , available at: http://www.sdchamber.org/thechamb/releases/07-0424.html, last accessed; May 2008.

Appendix C-55: North America - San Francisco (United States)

The multi-airport system that serves the San Francisco metropolitan region is composed of two primary airports; San Francisco/Intl (SFO-KSFO) and San Francisco/Oakland (OAK-KOAK) and one secondary airport; San Francisco/San Jose (SJC-KSJC).





a. San Francisco/Intl (SFO): Original airport (primary)

San Francisco/Intl is located 10 miles from the center of San Francisco. It opened in 1927. Major airport improvements were made in the 1950s with the construction of a central passenger terminal. Airport expansion and improvements continued during the 1970s with the construction of a new terminal dedicated to domestic flights.

Congestion of primary airports: San Francisco/Intl faces strong capacity constraints and congestion during Instrument Flight Rules (IFR) conditions[1]. These conditions are frequent in the Bay Area, with fog and limited visibility). In addition, the airport footprint is severely constrained. This limits any future runway addition and expansion. According

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[1] Source: Airport Technology website, *"San Francisco International Airport (SFO/KSFO), CA, USA"*, available at: http://www.airport-technology.com/projects/san_fran/, last accessed; April 2008.

to the 2003 Airport Capacity Demand / Demand Profiles report[1], the runway system at San Francisco/Intl was "near saturated at peak hours" in 2001.

b. San Francisco/Oakland (OAK): Primary airport emerged from the utilization of an existing airport

San Francisco/Oakland[2] is located in 11 miles from the city of San Francisco. It was constructed in 1927.

Entry of carriers (e.g. low-cost carriers): In 1937, San Francisco/Oakland gained connection with the east coast with United Air Lines introduction to service of DC-3 between San Francisco/Oakland and New York. Commercial flights were diverted to San Francisco/Intl in 1943 when the airport was taken over for military purposes. San Francisco/Oakland had limited service by legacy airlines and traffic was stagnating around 4 million passengers per year until the entry of Southwest airlines in 1989.

Upgrade of airport infrastructure: A new 6,200-foot runway was built in 1945. Additional improvements were made to the airport in the 1960s with the construction of a 10,000 foot runway and a new passenger terminal topped with a 10-story control tower. San Francisco/Oakland was also upgraded in the 1970s with the opening of a new international arrivals building.

Presence of secondary basins of population: San Francisco/Oakland is located 6 miles from the city center of Oakland (CA) which is a secondary basin of population in the San Francisco metropolitan region. In 2004, the Oakland city had a population of 399,484 (UN 2004) and the county of Alameda which covers most of the East Bay region of the San Francisco Bay Area had a population of 1,443,741 in 2000 (US census).

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[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[2] Source: Oakland airport website, available at: http://www.flyoakland.com/tex/history.shtml, last accessed: April 2008.

Congestion of primary airports: cf. San Francisco/Intl

c. San Francisco/San Jose (SJC): Emerged secondary airport

San Francisco/San Jose is located 38 miles south from the center of the city of San Francisco and north of the city of San Jose. It was constructed in 1945 and opened to civilian activities in 1965.

Entry of carriers (e.g. low-cost carriers): In 1988, American Airlines started offering scheduled service at San Francisco/San Jose. The entry of Southwest Airlines strongly stimulated the growth of the airport.

Presence of secondary basins of population: San Francisco/San Jose is located 2 miles from the city center of San Jose (CA) which represents a secondary basin of population in the San Francisco metropolitan region. In 2004, the city of San Jose had a population of 894,943 (UN 2004). In addition, the city of San Jose is part of the Santa Clara County (e.g. primary site of Silicon Valley) which had a population of 1,682,585 in 2000 (US census).

Congestion of primary airports: cf. San Francisco/Intl

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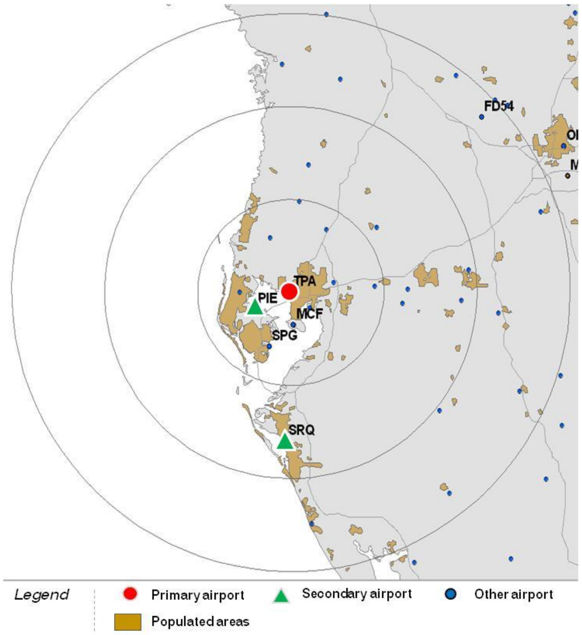
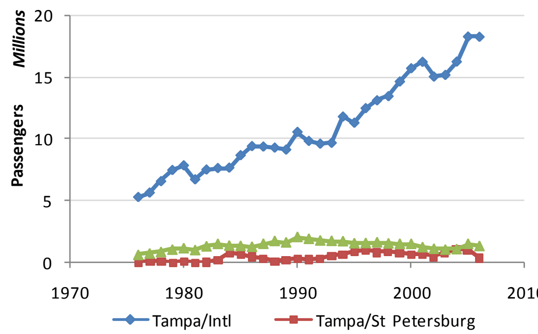
Appendix C-56: North America - Tampa (United States)

The multi-airport system that serves the region of Tampa is composed of one primary airport; Tampa/Intl (TPA-KTPA) and two secondary airports; Tampa/Sarasota (SRQ-KSRQ) and Tampa/St Petersburg (PIE-KPIE).





a. Tampa/Intl (TPA): Original primary airport

Tampa/Intl is located 5 miles from the center of the city of Tampa. It opened in 1971.

Congestion of primary airports: According to the 2003 Airport Capacity Demand / Demand Profiles report[1], the runway system had remaining capacity, but the apron and terminal at Tampa/Intl were "near saturated during peak hours" in 2001.

b. Tampa/St Petersburg (PIE): Emerged secondary airport

Tampa/St Petersburg is located 14 miles from the center of the city of Tampa. The airport was built in 1941.

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[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

Entry of carriers (e.g. low-cost carriers): Recent entry of Allegiant.

Changes of airport status; conversion from military to civil status: The airport started as a military flight-training base.

Upgrade of airport infrastructure: Since the 1940s, the airport went through several phases of expansion and improvements. The airport now features three intersecting runways of 8800 ft, 5500 ft and 5165 ft long and is spread over 2000 acres of land which are designated as a Foreign Trade Zone.

Presence of secondary basins of population: Due to the presence of water areas that constrain the direct access between the three airports in the region, the secondary basins of population play a key role. In addition, the airports have significant leisure traffic. Tampa/St Petersburg is located close Clearwater (i.e. population 108,687 in 2005[1]), located in the Pinellas County (i.e. population 928,031).

Congestion of primary airports: cf. Tampa/Intl

c. Tampa/Sarasota (SRQ): Emerged secondary airport

Tampa/Sarasota is located 38 miles from the center of the city of Tampa. Its construction started in 1939 and was achieved in 1942.

Changes of airport status; conversion from military to civil status: (World War II use) The Army Air Corps used the airport as a fighter pilot training base during World War II and then returned it to the authority in 1947.

Upgrade of airport infrastructure: The main runway was extended to its actual length in 2002.

[1] Data source: U.S. Census data (2005).

Presence of secondary basins of population: Due to the presence of water areas that constrain the direct access between the three airports in the region, the secondary basins of population play a key role. Tampa/Sarasota is located in the county of Sarasota (i.e. population 326,000).

Congestion of primary airports: cf. Tampa/Intl.

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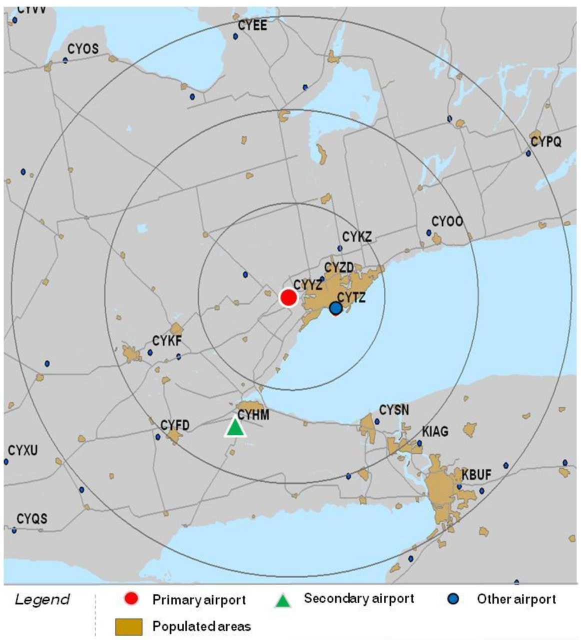
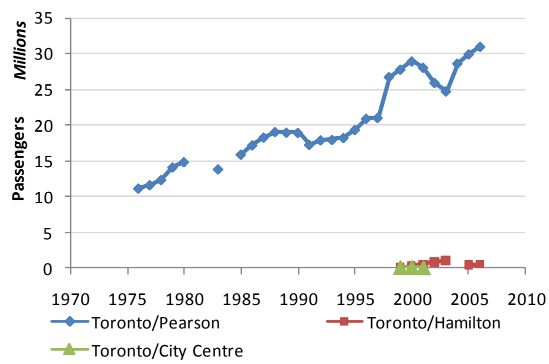
Appendix C-57: North America - Toronto (Canada)

The multi-airport system that serves the Toronto metropolitan region is composed of one primary airport; Toronto/Pearson (YYZ-CYYZ) and one secondary airport; Toronto/Hamilton (YHM-CYHM). The multi-airport system also features one airport located in the center of the city, Toronto/City Centre. This airport did not meet the 500,000 passenger criteria in 2006 but that could re-emerge and become a secondary airport (i.e. recent entry and route development by Porter Airlines).





a. Toronto/Pearson (YYZ): Original airport (primary)

Toronto/Pearson is located 12 miles from the center of the city of Toronto. It was opened in 1939. In 1996, following the national trend of transfer of ownership of airports to public or private airport authorities in Canada (i.e. National Airports Policy), the Government of Canada transferred the management and operation of the airport to the Greater Toronto Airports Authority (GTAA)[1].

[1] Source: Airport Technology website, *"Toronto Pearson International Airport (YYZ/CYYZ), Canada"*, available at: http://www.airport-technology.com/projects/toronto/, last accessed; April 2008.

Congestion of primary airports: According to the 2003, ACI/ATAG/IATA Airport Capacity Demand / Demand Profiles report[1], the runway, apron and terminal of Toronto/Pearson airport were "near saturated at peak hours" in 2001. Toronto/Pearson is "undergoing a ten-year airport development programme (ADP), requiring investments of CA$4.4 billion in order to meet growing demand."[2].

b. Toronto/Hamilton (YHM): Emerged secondary airport

Toronto/Hamilton is located 44 miles southwest of the center of the city of Toronto. It was built in 1940 as a Royal Canadian Air Force base[3].

Entry of carriers (e.g. low-cost carriers): In 1969, Nordair established a commercial air service at Toronto/Hamilton and obtained authority for a Toronto/Hamilton to Montreal/Trudeau and Toronto/Hamilton to Pittsburgh service. The entry of Westjet in 2000 and Globespan in 2007 led to strong increases of passenger traffic. However, Westjet transferred some of its flights to Toronto/Pearson.

Changes of airport status; conversion from military to civil status: During World War II, the airport was used of as an Air Training facility. After the war, Toronto/Hamilton was gradually transferred to civil use. In 1963, the Canadian Department of National Defense declared the intention of decommissioning Toronto/Hamilton. It transferred its ownership and control to the Department of Transportation. Military use stopped in 1964. The City of Hamilton assumed responsibility for the maintenance and operation of the airport in 1967.

Upgrade of airport infrastructure: Once the airport was transferred to civil use, several infrastructure improvements were performed. In 1980, plans to upgrade existing airport

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[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

[2] Source: Airport Technology website, *"Toronto Pearson International Airport (YYZ/CYYZ), Canada"*, available at: http://www.airport-technology.com/projects/toronto/, last accessed; April 2008.

[3] Source: Hamilton International Airport, *"About the airport",* available at: http://www.flyhi.ca/about/history.shtml, last accessed: April 2008.

facilities were established; the construction of a new runway, new and improved taxiways, expanded aprons and air terminal. Construction was completed in 1986.

Presence of secondary basins of population: Toronto/Hamilton is located 7 miles southwest of the city of Hamilton, Ontario (population: 504,559[1]).

Congestion of primary airports: cf. Toronto/Pearson.

Role of ownership and management of airports: In 1995, following the national trend of transfer of ownership of airports to local public or private airport authorities in Canada (i.e. National Airports Policy), the region signed an agreement to enter into formal negotiations with Transport Canada to transfer ownership of the airport. In parallel, region issued a request for proposal for private sector involvement in the management, marketing and development of the airport. TradePort International Corporation was awarded the management contract under the terms of a 40-year lease with the City of Hamilton.

c. Toronto/City Centre (YTZ): Potential secondary airport (from an original airport)

Toronto/City Centre is located 4 miles from the center of the Toronto city. It opened in 1939. Due to its proximity to the city center, it remains an attractive airport. However, its access (i.e. airfield access) is constrained by short runways (i.e. the longest runway is 4,000 ft). Only commercial turboprop aircraft can access the airport. Toronto/City Centre has seen some rebound of traffic in the recent years, with the entry and development of domestic routes by Porter Airlines which uses Q400 turboprops compatible with the runway infrastructure.

[1] Data source: Statistics Canada, 2006, available at: http://www12.statcan.ca/english/census/index.cfm, last accessed: April 2008.

d. Pickering Airport (potential future airport)

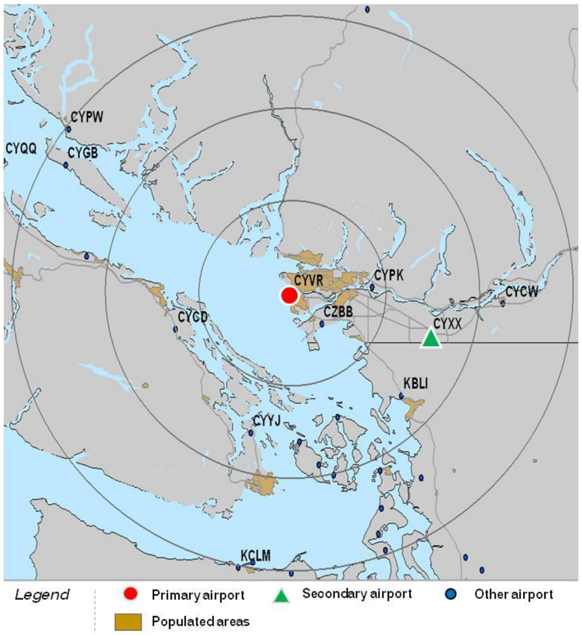
Pickering Airport was a proposed airport located east of Toronto, established in 1972.

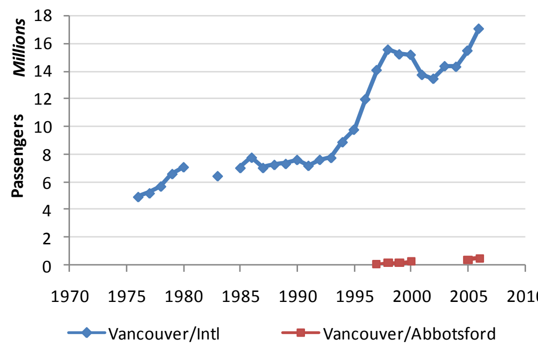
Protection of future airport sites:[1] In 1972, the Canadian government expropriated land (i.e. approximately 7,350 hectares) east of Toronto for a second major airport. The intent was to retain the lands for a potential international airport site for the greater Metropolitan Toronto region and relieve the congestion at Toronto/Pearson. The project was postponed in 1975 due partly to community opposition, but GTAA revived the plans in 2004. In 1975, plans for a "Minimum International Airport" were started but the construction was stopped due to the provincial government's withdrawal of support for essential off-site arrangements such as roads, water and sewer services. While the lands were placed under the administration of Public Works and Government Services Canada (PWGSC), several occasions of selling a portion of land were deferred between 1984 and 1994. In 1994, under the new National Airports Policy (NAP) which, the federal government announced it would maintain its role as regulator and but limit its role of owner and operator as landlord. In 1998, Transport Minister David Collenette initiated regulatory action to protect the option of developing a potential, future airport. In 1998, a multi-stakeholder committee comprised of affected municipal, local interest groups, and Transport Canada, was established to explore alternatives to federal airport zoning regulations. In 2001, an agreement was reached to delay the decision to build a reliever airport on the Pickering Lands. The site remains however reserved for possible future aviation requirements.

[1] Source: Transport Canada, Pickering Airport Site Zoning Regulations, available at: http://www.tc.gc.ca/ontarioregion/pickering/azr/en/menu.htm, last accessed; March 2008.

Appendix C-58: North America - Vancouver (Canada)

The multi-airport system that serves the region of Vancouver is composed of one primary airport; Vancouver/Intl (YVR-CYVR) and one secondary airport; Vancouver/Abbotsford (YXX-CYXX).





a. Vancouver/Intl (YVR): Original airport (primary)

Vancouver/Intl is located 5 miles from the city of Vancouver. It was built in 1929. During World War II, the airport was expanded, leased to the Federal Government and operated by the Departments of National Defense and Transport. After WWII, the City of Vancouver resumed control of the airport. The airport was further expanded in the 1960s. In 1992, the airport was transferred from the Federal Government to local community-based, not-for-profit organizations (YVR).

Congestion of primary airports: According to the 2003, Airport Capacity Demand / Demand Profiles report[1], the runway, apron and terminal of Vancouver/Intl airport were "near saturated at peak hours" in 2001.

[1] Data source: Airports Council International – Air Transport Action Group – International Air Transport Association, (2003), "Airport Capacity Demand / Demand Profiles", Geneva, Switzerland

b. Vancouver/Abbotsford (YXX): Emerged secondary airport

Vancouver/Abbotsford is located 36 miles from the city of Vancouver. It was built in 1943, by the Royal Canadian Air Force (RCAF).

Entry of carriers (e.g. low-cost carriers): In 1997, WestJet (i.e. major Canadian low-cost carrier) started to offer scheduled service at Vancouver/Abbotsford. BC West Air is also serving the airport.

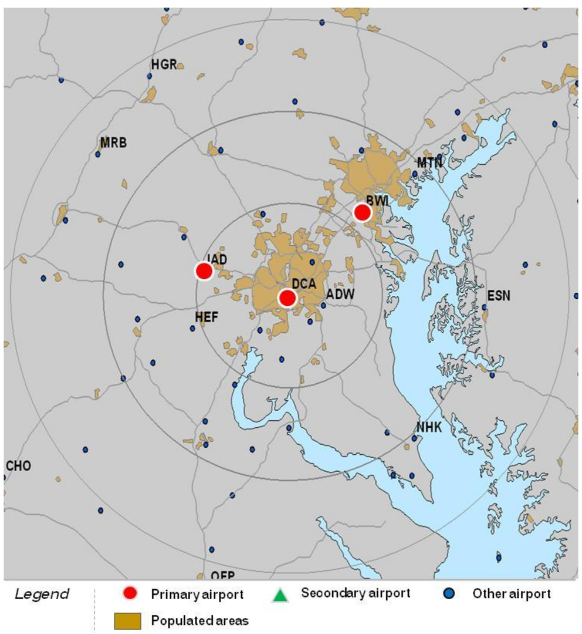
Changes of airport status; conversion from military to civil status: Vancouver/Abbotsford was used as a British Commonwealth Air Training Plan airport (i.e. No. 24 Elementary Flying Training School). In 1958, Vancouver/Abbotsford was officially transferred to the Department of Transport. In 1997, following the national trend of transfer of ownership of airports to public or private airport authorities, the Canadian Department of Transport transferred ownership of Vancouver/Abbotsford to the City of Abbotsford.

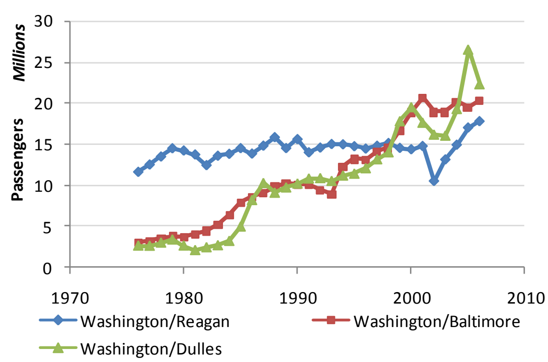
Upgrade of airport infrastructure: In 1963, runway 07-25 was extended to 8000 ft to accommodate larger aircraft. In 2005, the main runway (i.e. 07-25) was further extended to 9,600 feet.

Congestion of primary airports: cf. Vancouver/Intl

Appendix C-59: North America - Washington (United States)

The multi-airport system that serves the metropolitan region of Washington is composed of three primary airports; Washington/Reagan (DCA-KDCA), Washington/Dulles (IAD-KIAD) and Washington/Baltimore (BWI-KBWI). While Washington/Reagan is the original airport in the metropolitan region, Washington/Dulles emerged as primary airport through a construction phase in the 1970s and Washington/Baltimore emerged as primary airport from the utilization of existing airport infrastructure is great part due to the entry of a low-cost carrier (i.e. Southwest).





a. Washington/Reagan (DCA): Original airport (primary)

Washington/Reagan is located 3 miles from the center of the city of Washington, DC. It opened in 1941 as a replacement for Washington-Hoover which was located on the current site of the Pentagon. It was expanded over the following years and reached its current size in 1955 with a final expansion phase.

Role of regulatory and political factors: By 1979, political factors strongly affected the proper development of Washington/Reagan. This airport along with Washington/Dulles, were the only two airports in the United States under government control and the airport faced issues due to increase in traffic and limited funds for expansion since revenues went to federal budgets. In the 1980s, Secretary for Transportation Elizabeth Hanford

Dole managed to have the transfer of authority from Congress to the new and independent Metropolitan Washington Airports Authority. The new authority was put in place by President Ronald Reagan in 1987. The benefits of this political battle were reflected in the opening of new Terminal B and C that opened a decade later in 1997.

Congestion of primary airports: Washington/Reagan was one of three slot restricted airports in the United States in 2008. Similarly to New York/LaGuardia, it has a perimeter rule that was established in 1969. With a maximum runway length of 6,869 ft, Washington/Reagan could not host large commercial jets. Those had to be accommodated at other airports in the region with longer runways (i.e. Washington/Dulles and Washington/Baltimore).

The footprint of Washington/Reagan is heavily constrained due to urban development on the west side and the Potomac River on other sides. With three intersecting runways, there is no available space in the current footprint to add runway capacity[1].

Environmental constraints: Due to its proximity to downtown Washington DC, the airport has also been subject to pressure to reduce noise. The perimeter rule established in 1969 was also a mechanism by which larger aircraft were restricted from using the airport and minimize noise generation.

b. Washington/Baltimore (BWI): Primary airport

Washington/Baltimore[2] is located in the State of Maryland, 26 miles north of the center of Washington, D.C. It opened in 1950. Major infrastructure improvements were performed started in 1974 and were completed in 1979 and included the remodeling of the terminal.

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[1] Source: Airport Technology website, *"B Ronald Reagan Washington National Airport (DCA/KDCA), DC, USA"*, available at: http://www.airport-technology.com/projects/ronaldreagan/, last accessed; April 2008.

[2] Source: Baltimore Washington International website, *"BWI History At A Glance"*, available at: http://www.bwiairport.com/about_bwi/bwi_timeline/, last accessed; April 2008.

Entry of carriers (e.g. low-cost carriers): In 1993, Southwest Airlines selected Washington/Baltimore as its first east coast gateway airport which led to record-breaking passenger growth of 40% the first year and 36% the second year.

Upgrade of airport infrastructure: Due to the increase in traffic triggering the need to expand the airport, the airfield capacity was increased with the completion of an extension to runway 10-28. In 2000, Washington/Baltimore started a five-year, $1.8 billion expansion and improvement plan[1].

c. Washington/Dulles (IAD): Primary airport emerged through the construction of a new airport

Washington/Dulles[2] is located 24 miles west of Washington, DC.

Identification of a need to build a new airport: After the end of World War II, the need to open a new airport was felt in order to meet the growing demand for air transportation. Congress passed the second Washington Airport Act of 1950 that was amended in 1958.

Planning, Financing and Construction of new airport: The construction of the airport started in September 1958 and opened, four years late in 1962. It featured two north-south parallel runways, each 11,500 feet long and separated by 6,700 feet and a third northwest-southeast runway, 10,000 feet long. In addition to airport infrastructure, a new access highway as part of the airport development project was constructed providing good ground connectivity. The first expansion was completed in 1977 with the widening of the jet parking ramp. In 1982, terminal improvements were performed in order to accommodate more passengers. In 1998, the first permanent concourse was completed and a concourse for regional aircraft opened in 1999.

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[1] Source: Airport Technology website, *"Baltimore-Washington International Thurgood Marshall Airport (BWI/KBWI), MD, USA"*, available at: http://www.airport-technology.com/projects/baltimore_expansion/, last accessed; April 2008.

[2] Source: Metropolitan Washington Airport Authority website, available at: http://www.metwashairports.com/Dulles/history.htm, last accessed: April 2008.

Transfer of traffic/Entry of carriers: No mandatory transfer of traffic policy was established and the primary airport in the region, at the time, Washington/Reagan remained opened. As a result, the growth of traffic at Washington/Dulles was delayed compared to originally plan. To this respect, Washington/Dulles is often referred to as a "white elephant" since it remained little utilized for nearly 20 years[1].

Congestion of primary airports and limitations of existing airports: cf. Washington/Reagan

Availability and acquisition of land area in the metropolitan region: At the time of the construction, large land areas were available at the selected site of Washington/Dulles. With the development and growth of Washington/Dulles, urban, residential and industrial areas developed around the airport.

Role of regulatory and political factors: Political factors strongly affected the development of Washington/Dulles and Washington/Reagan. They were the only two airports in the United States under government control in 1979. In the 1980s, Secretary for Transportation Elizabeth Hanford Dole managed to have the transfer of authority from Congress to the new and independent Metropolitan Washington Airports Authority. The new authority was put in place by President Ronald Reagan in 1987.

[1] Source: (de Neufville, 1995).